Lenté Dreyer

IMPORTANT STUFF

FERMI SUMMER SCHOOL 2019

Fermi Gamma-ray Space Telescope

Students all around the world is coming together in Delaware, USA to use some of the Fermi tools. Students spend time working directly with experts in instrumentation, analysis, theory and modeling to develop and extend their own research projects.

read more >

The Virden Centre is hosting A BBQ on the patio !

Tonight @ 6:30

read more >

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NASSP NATIONAL ASTROPHYSICS AND SPACE SCIENCE PROGRAMME

NEWS

STUDENT SET FIRE ON BBQ WITH LIQUID AND HOME-MADE TORCH

June 3, 2019

To students, Bolt* and Robert" accidentally set a BBQ on fire due to inexperience and bad judgement during this years Fermi summer school in Delaware.
(* - names have been changed to protect the privacy of the individuals)

read more >

Black Hole Image Makes History; NASA Telescopes Coordinated Observations

April 10, 2019

Using the Event Horizon Telescope, scientists obtained an image of the black hole at the center of galaxy M87, outlined by emission from hot gas swirling around it under the influence of strong gravity near its event horizon.

read more >

Event Horizon Telescope collaboration et al.

Lenté Dreyer

Group: High-energy Astrophysics

Position: second year M.Sc. student

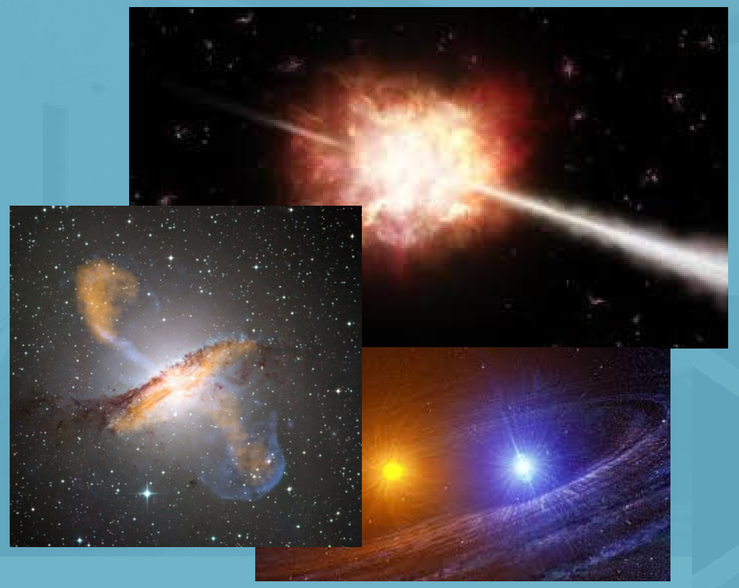
supervisor: Prof. Markus Böttcher

Lenté Dreyer

NRF SARChI Chair of Astrophysics and Space Physics
Centre for Space Research

National Research Foundation

Research interests



Memberships

H.E.S.S.

cta
cherenkov telescope array

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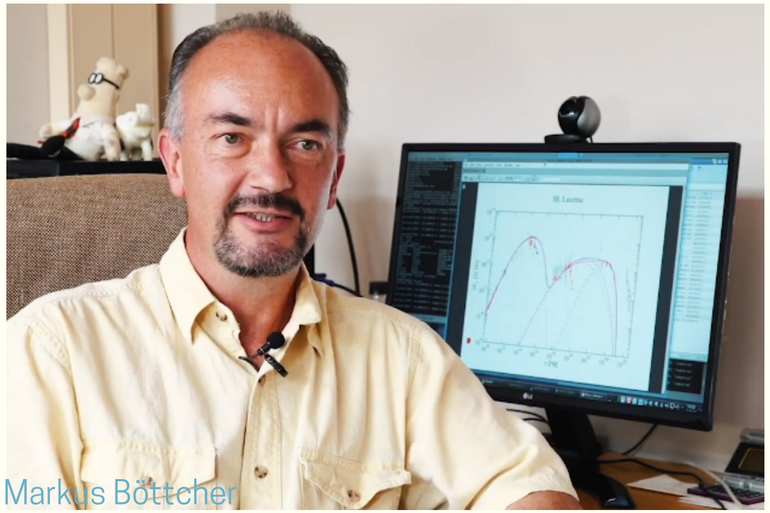
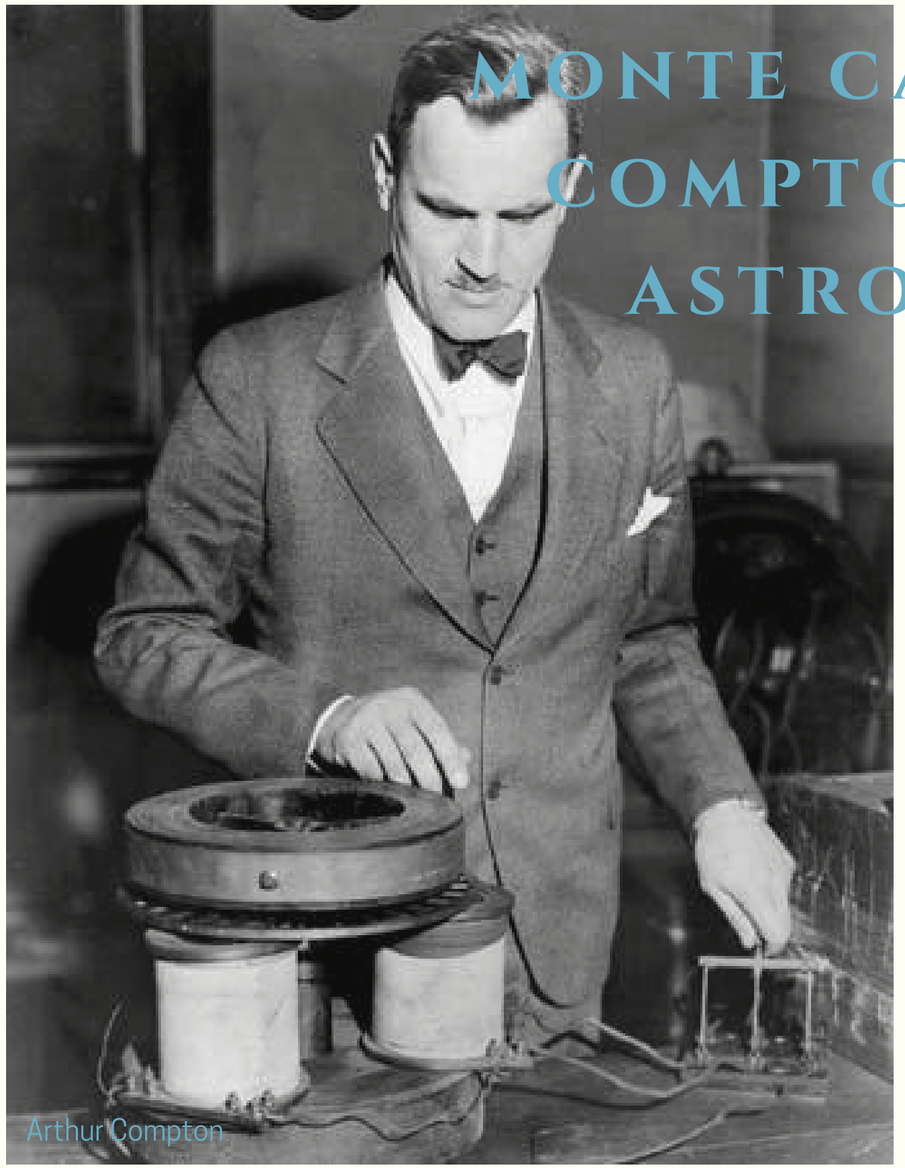


Markus Böttcher



Arthur Compton

MONTE CARLO SIMULATIONS OF COMPTON POLARIZATION IN ASTROPHYSICAL SOURCES

SUPERVISOR: Prof. Markus Böttcher

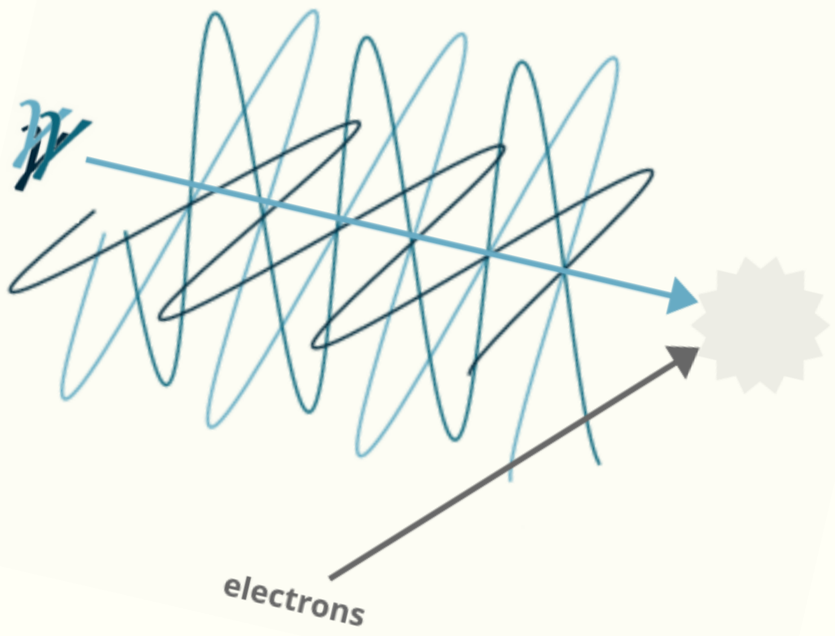
STATUS: incomplete

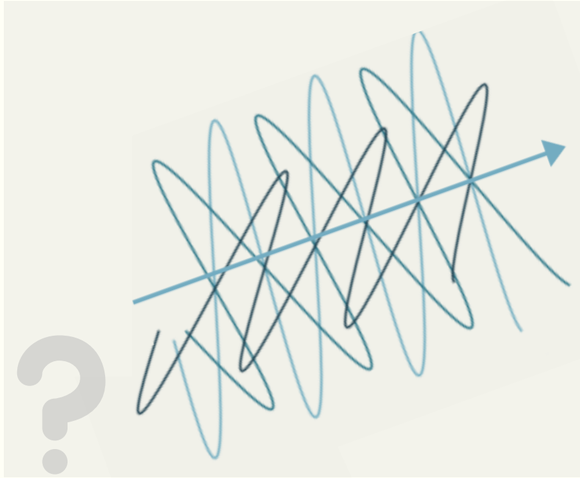
DUE DATE: October 2019

read more >

MONTE CARLO SIMULATIONS OF COMPTON POLARIZATION IN ASTROPHYSICAL SOURCES

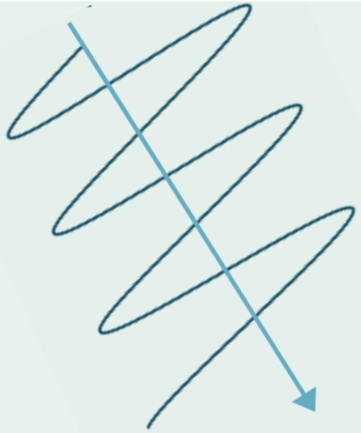
WHAT IS THE POLARIZATION OF HIGH-ENERGY PHOTONS DUE TO COMPTON SCATTERING?





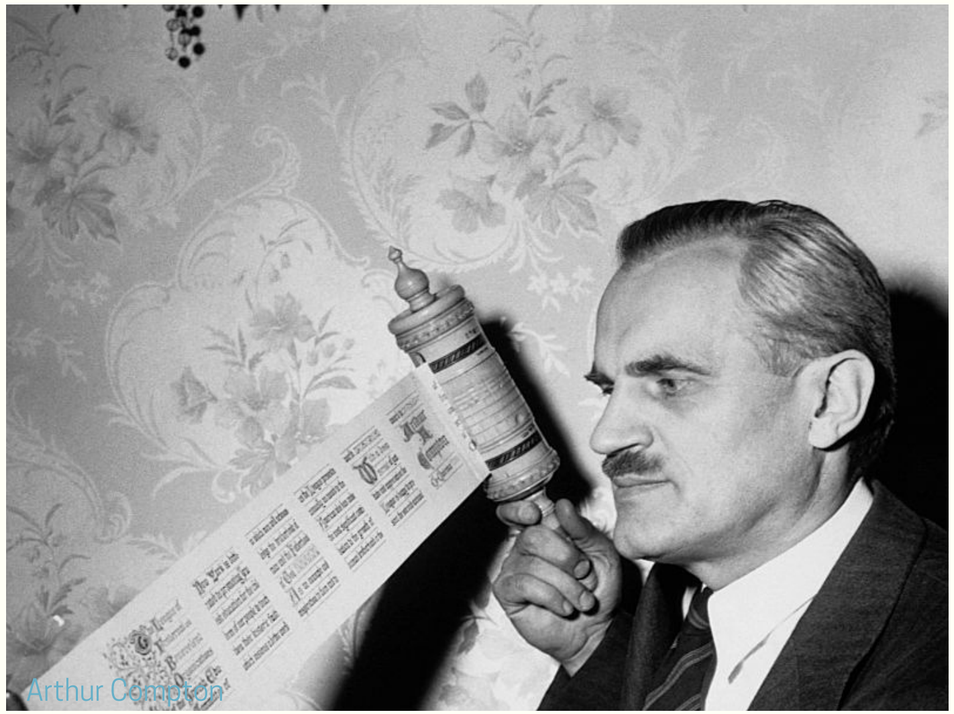
unpolarized

electric-field
is oscillating in
different directions



polarized

electric-field
is oscillating in
one direction



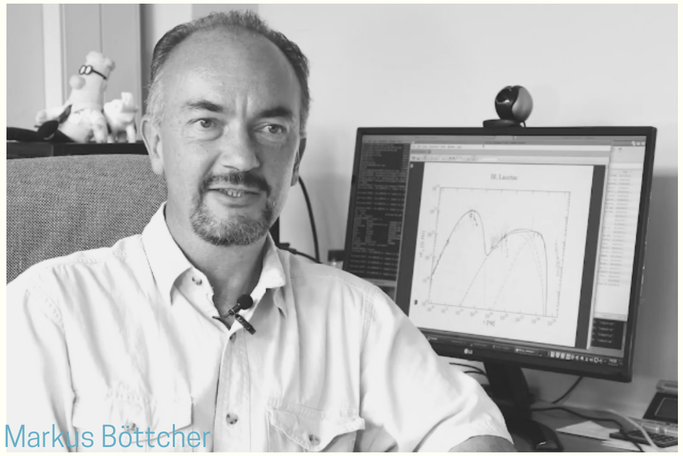
Arthur Compton

TLDR: QOUTE SMARTER PEOPLE

CONVINCE ME

Vannevar Bush and Arthur Compton

TLDR: QOUTE SMARTER PEOPLE



Markus Böttcher

"...there are currently great prospects for future detection of high-energy (X-ray and gamma-ray) polarization from blazars. Thus, **it is timely to consider model predictions of such high-energy polarization.**"

"High-energy polarization **can thus be used as a diagnostic between leptonic and hadronic models.**"

BÖTTCHER, 2019

Not convinced?

TLDR: QOUTE SMARTER PEOPLE

HOLDER, 2019

A few things to think about (far from exhaustive)...

What is the power source?	Accretion-powered jet	Pulsar wind		
What is the particle acceleration mechanism?	Jet shocks	Magnetic reconnection	Wind shocks	
What are the dominant particles?	Hadronic	Leptonic		
How are the γ-rays produced?	Pion decay	Inverse Compton	Curvature Radiation	
Where are the γ-rays produced?	Near the jet	Wind collision region	Pulsar wind zone	Circumstellar environment / Pulsar magnetosphere
What modulates the flux?	Geometry	Photon fields	Matter density	B-fields
Other effects?	Wind clumping	Pair cascades	Doppler boosting	

Many of these are not mutually exclusive...

TLDR: QOUTE SMARTER PEOPLE

HOLDER, 2019

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TLDR: QOUTE SMARTER PEOPLE

HOLDER, 2019

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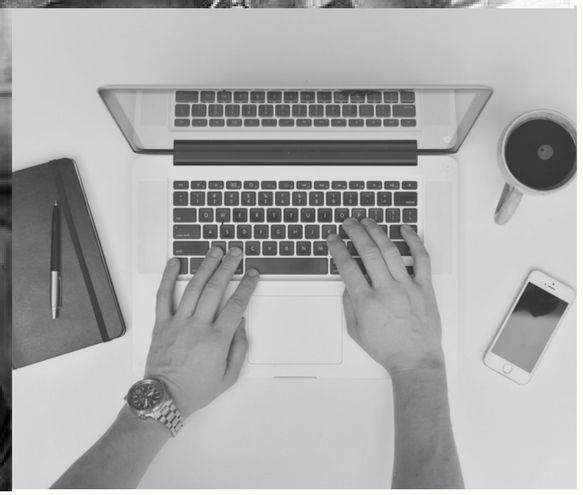
Many of these are not mutually exclusive...

John Von Neumann, Richard Feynman, and Stanislaw Ulam

Nicholas Metropolis



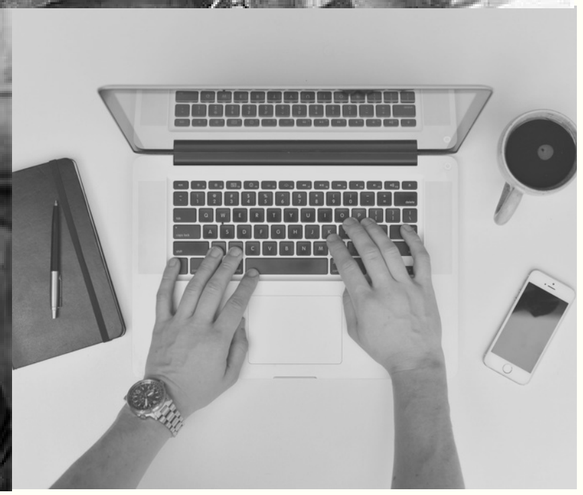
MONTE CARLO METHODS

Monte Carlo methods is a class of computational algorithms that rely on the randomness and repetitive nature of the process to produce numerical results

read more >

John Von Neumann, Richard Feynman, and Stanislaw Ulam

Nicholas Metropolis



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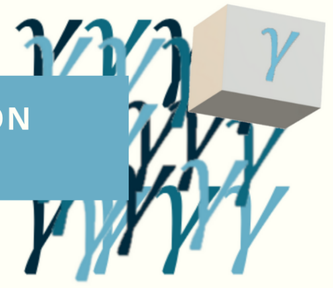
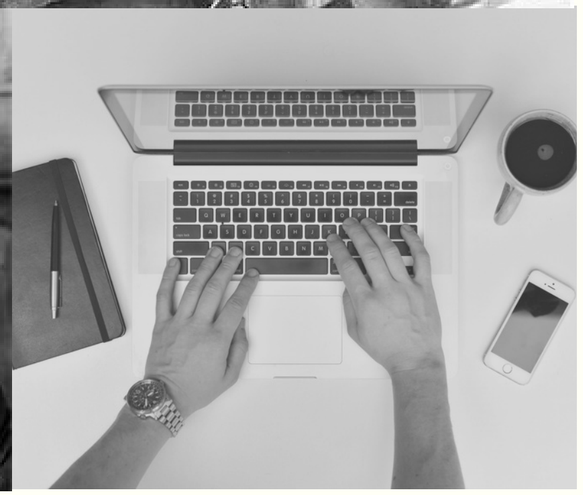
PHOTON PACKET APPROACH

SINGLE PHOTON APPROACH



John Von Neumann, Richard Feynman, and Stanislaw Ulam

Nicholas Metropolis



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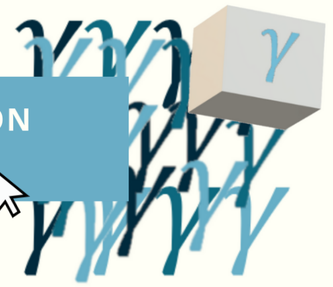


SINGLE PHOTON APPROACH

GENERATE A SEED PHOTON

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

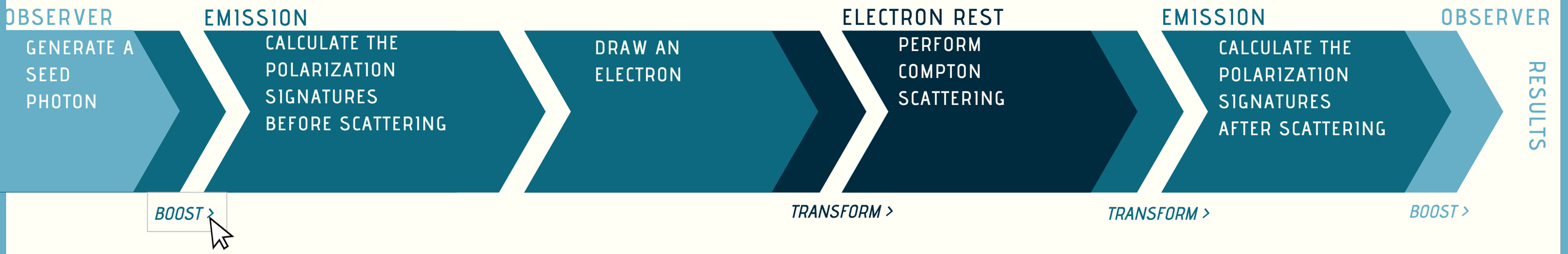
PERFORM COMPTON SCATTERING

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

RESULTS

view frame of refreneces >

SINGLE PHOTON APPROACH



SINGLE PHOTON APPROACH

OBSERVER
GENERATE A SEED PHOTON

EMISSION
CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

BOOST >

DRAW AN ELECTRON

TRANSFORM >

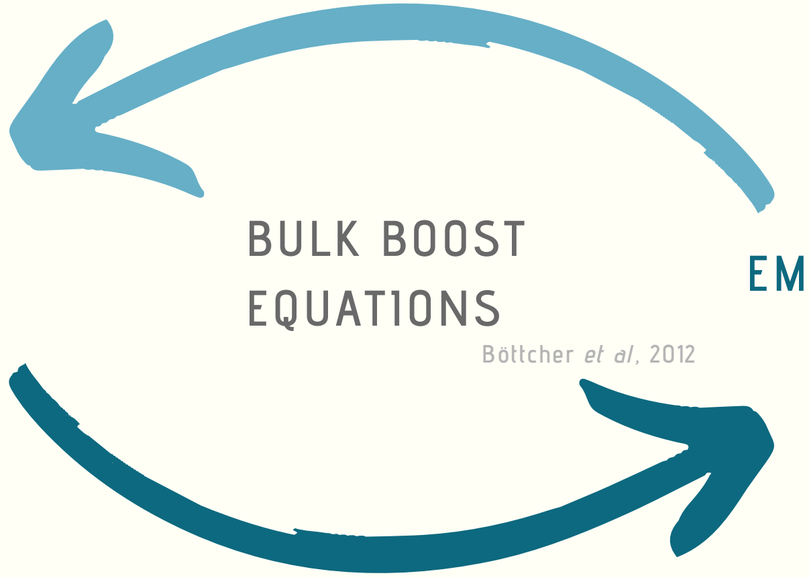
ELECTRON REST
PERFORM COMPTON SCATTERING

TRANSFORM >

EMISSION
CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

BOOST >

OBSERVER
RESULTS



Böttcher *et al*, 2012

view input parameters >

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

ELECTRON REST

PERFORM COMPTON SCATTERING

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

OBSERVER

RESULTS

BOOST >

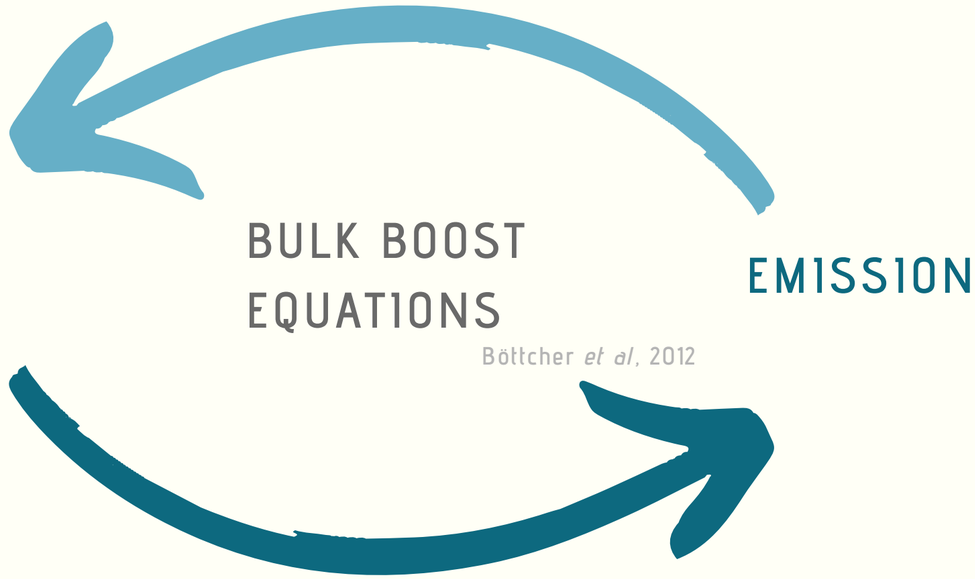
Γ = 10

TRANSFORM >

TRANSFORM >

BOOST >

Γ = 10



Böttcher *et al*, 2012

view input parameters > Γ = 10

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

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CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

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PERFORM COMPTON SCATTERING

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

OBSERVER

RESULTS

WILL THE PHOTON UNDERGO COMPTON SCATTERING?

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?

Monte Carlo methods >

SINGLE PHOTON APPROACH

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OBSERVER

RESULTS

WILL THE PHOTON UNDERGO COMPTON SCATTERING?

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?

$$P_{scatt} = \frac{\sigma_{KN}}{\sigma_T}$$

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

ELECTRON REST

PERFORM COMPTON SCATTERING

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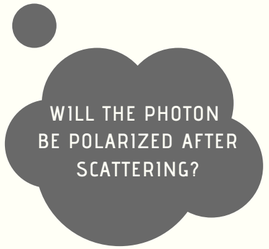
WILL THE PHOTON UNDERGO COMPTON SCATTERING?

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?

$$P_{pol} = \Pi_{scatt}$$

SINGLE PHOTON APPROACH



Monte Carlo methods >

SINGLE PHOTON APPROACH

OBSERVER

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DRAW AN ELECTRON

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WILL THE PHOTON UNDERGO COMPTON SCATTERING?

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?

OBSERVER

RESULTS

$$P \begin{cases} < \xi[0,1] \rightarrow \text{NO} \\ > \xi[0,1] \rightarrow \text{YES} \end{cases}$$

SINGLE PHOTON APPROACH

OBSERVER

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EMISSION

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OBSERVER

RESULTS

DIRECTION

ISOTROPIC DISTRIBUTION

ENERGY

BLACK-BODY DISTRIBUTION

view for all photons >

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

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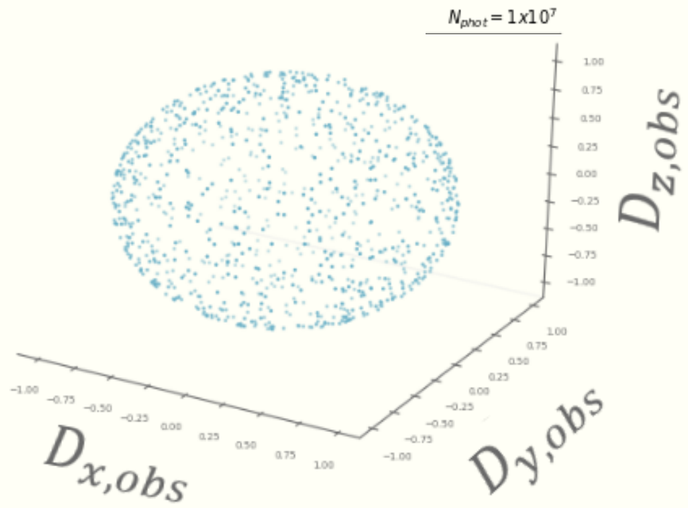
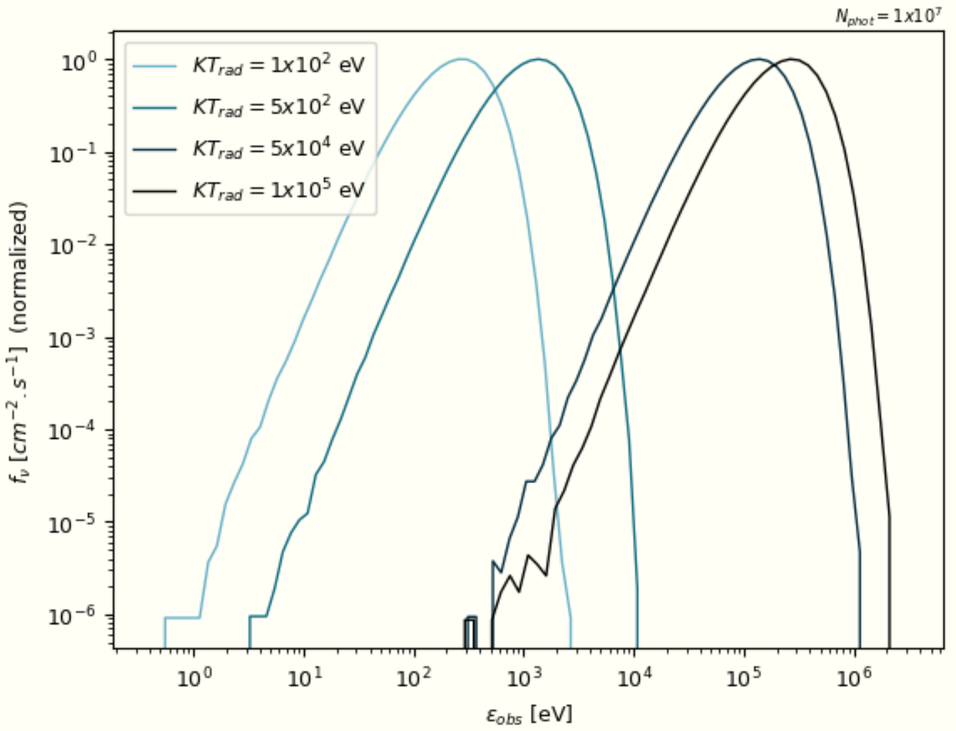


view input parameters >

ENERGY

BLACK-BODY DISTRIBUTION



SINGLE PHOTON APPROACH

OBSERVER → GENERATE A SEED PHOTON

EMISSION → CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

→ DRAW AN ELECTRON

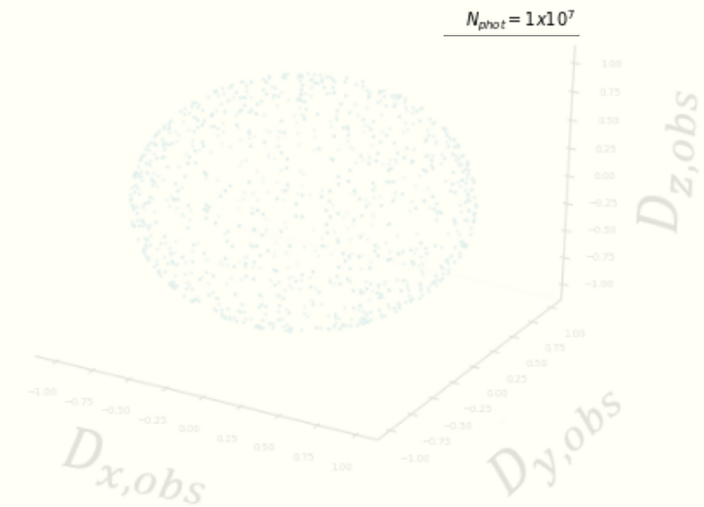
ELECTRON REST → PERFORM COMPTON SCATTERING

EMISSION → CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

OBSERVER → RESULTS

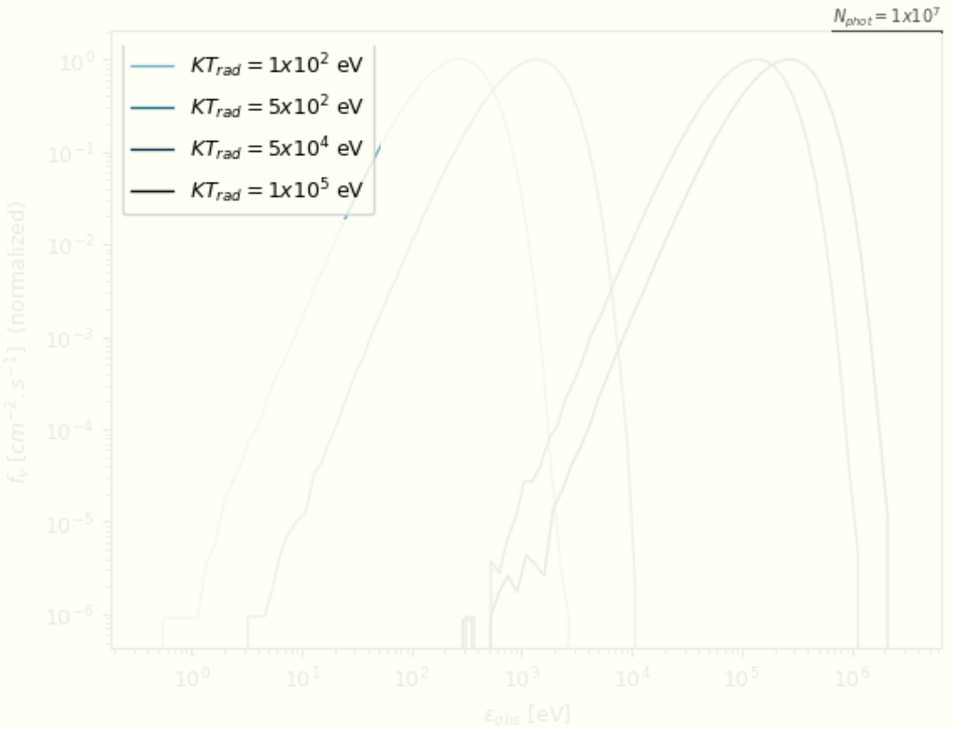
DIRECTION

ISOTROPIC DISTRIBUTION



ENERGY

BLACK-BODY DISTRIBUTION



view input parameters > $\Gamma = 10$; KT_{rad}

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

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ELECTRON REST

PERFORM COMPTON SCATTERING

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

OBSERVER

RESULTS

DIRECTION

ISOTROPIC DISTRIBUTION

ENERGY

THERMAL DISTRIBUTION

view for all electrons >

SINGLE PHOTON APPROACH

OBSERVER → EMISSION → ELECTRON REST → EMISSION → OBSERVER

GENERATE A SEED PHOTON

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

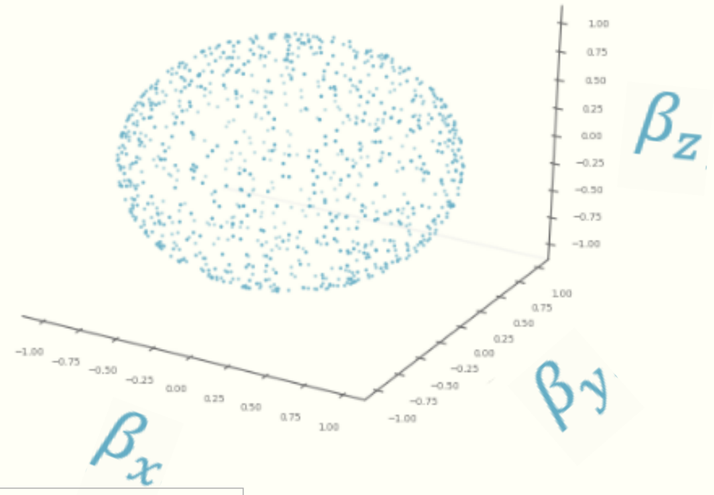
PERFORM COMPTON SCATTERING

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

RESULTS

DIRECTION

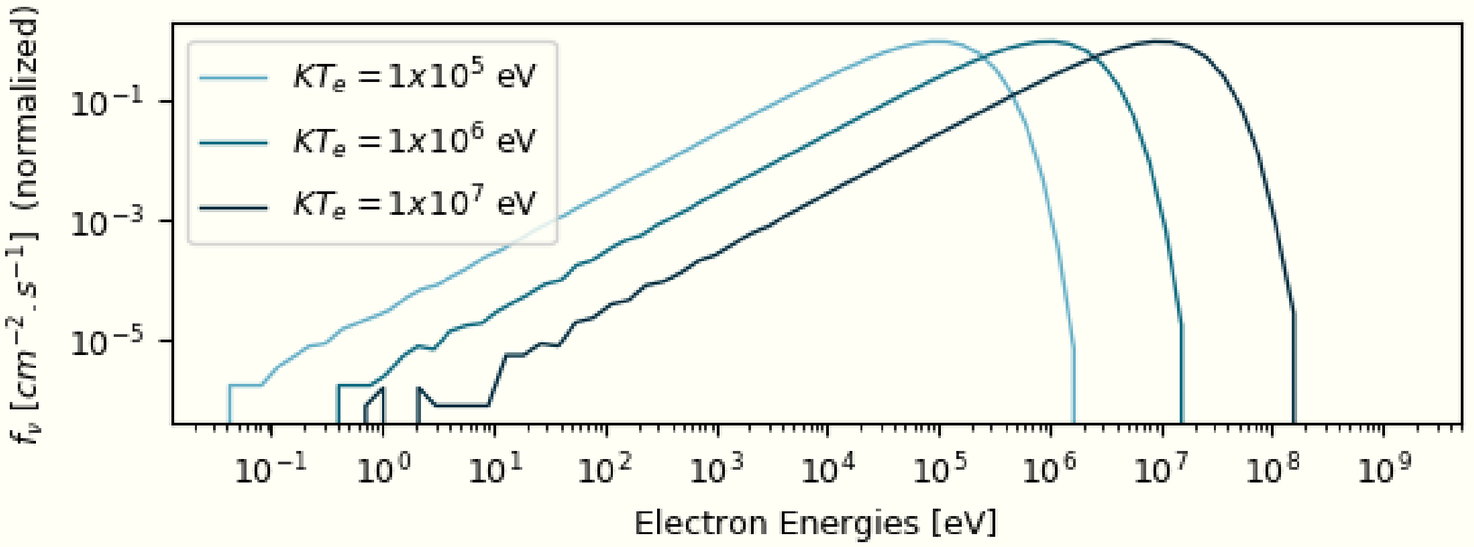
ISOTROPIC DISTRIBUTION



view input parameters >

ENERGY

THERMAL DISTRIBUTION



SINGLE PHOTON APPROACH

OBSERVER → GENERATE A SEED PHOTON

EMISSION → CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

ELECTRON REST → PERFORM COMPTON SCATTERING

EMISSION → CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

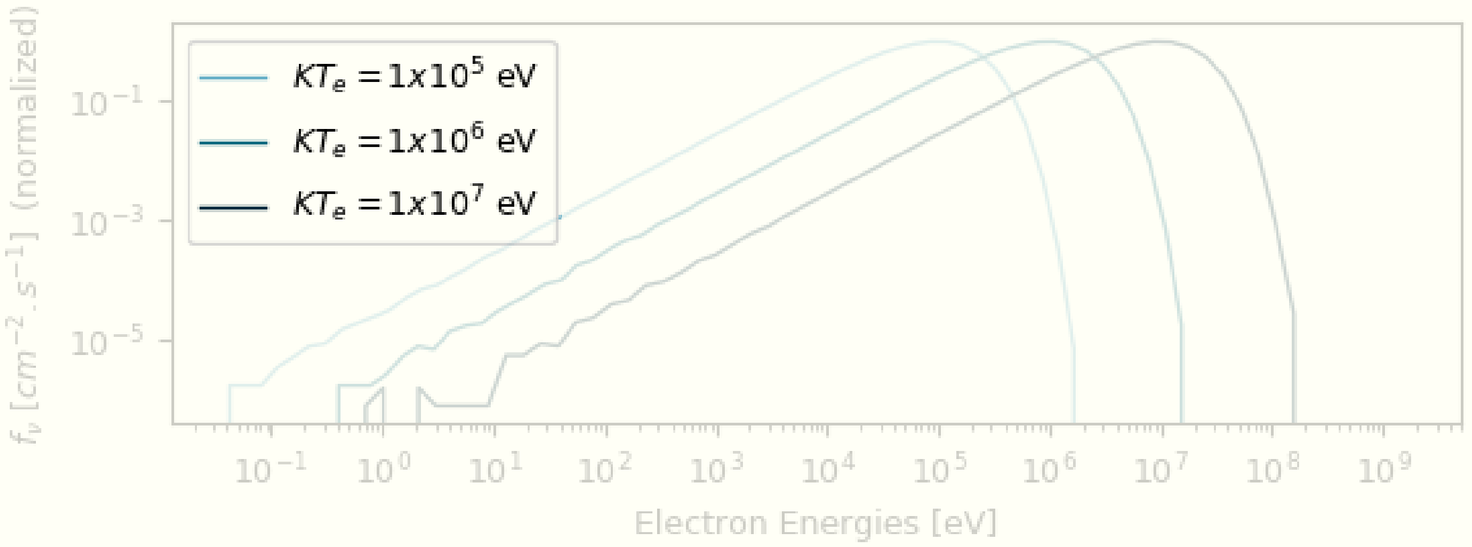
OBSERVER → RESULTS

DIRECTION

ISOTROPIC DISTRIBUTION

ENERGY

THERMAL DISTRIBUTION



view input parameters > Γ = 10; KT_{rad} and KT_e

SINGLE PHOTON APPROACH

OBSERVER → EMISSION → ELECTRON REST → EMISSION → OBSERVER → RESULTS

GENERATE A SEED PHOTON

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

PERFORM COMPTON SCATTERING

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

CALCULATE THE ENERGY OF THE PHOTON AFTER SCATTERING

$$\epsilon'_e = \frac{\epsilon_e}{1 + \frac{\epsilon_e}{m_e c^2}(1 - \cos\Theta_{sc})}$$

CALCULATE THE DIRECTION OF THE PHOTON AFTER SCATTERING

$$D'_{e,x} = D_{e,x}\cos\Theta_{sc} + P_{e,x}\sin\Theta_{sc}\cos\Phi_{sc} + \sin\Theta_{sc}\sin\Phi_{sc}\,(D_{e,y}P_{e,z} - D_{e,z}P_{e,y})$$

$$D'_{e,y} = D_{e,y}\cos\Theta_{sc} + P_{e,y}\sin\Theta_{sc}\cos\Phi_{sc} + \sin\Theta_{sc}\sin\Phi_{sc}\,(D_{e,z}P_{e,x} - D_{e,x}P_{e,z})$$

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SINGLE PHOTON APPROACH

OBSERVER → EMISSION → ELECTRON REST → EMISSION → OBSERVER → RESULTS

GENERATE A SEED PHOTON

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

PERFORM COMPTON SCATTERING

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

CALCULATE THE ENERGY OF THE PHOTON AFTER SCATTERING

ANGLE BETWEEN THE SEED AND SCATTERED PHOTON

$$\epsilon'_e = \frac{\epsilon_e}{1 + \frac{\epsilon_e}{m_e c^2}(1 - \cos\Theta_{sc})}$$

view for all photons >

CALCULATE THE DIRECTION OF THE PHOTON AFTER SCATTERING

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SINGLE PHOTON APPROACH

OBSERVER → EMISSION → ELECTRON REST → EMISSION → OBSERVER → RESULTS

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PERFORM COMPTON SCATTERING

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CALCULATE THE ENERGY OF THE PHOTON AFTER SCATTERING

ANGLE BETWEEN THE SEED AND SCATTERED PHOTON

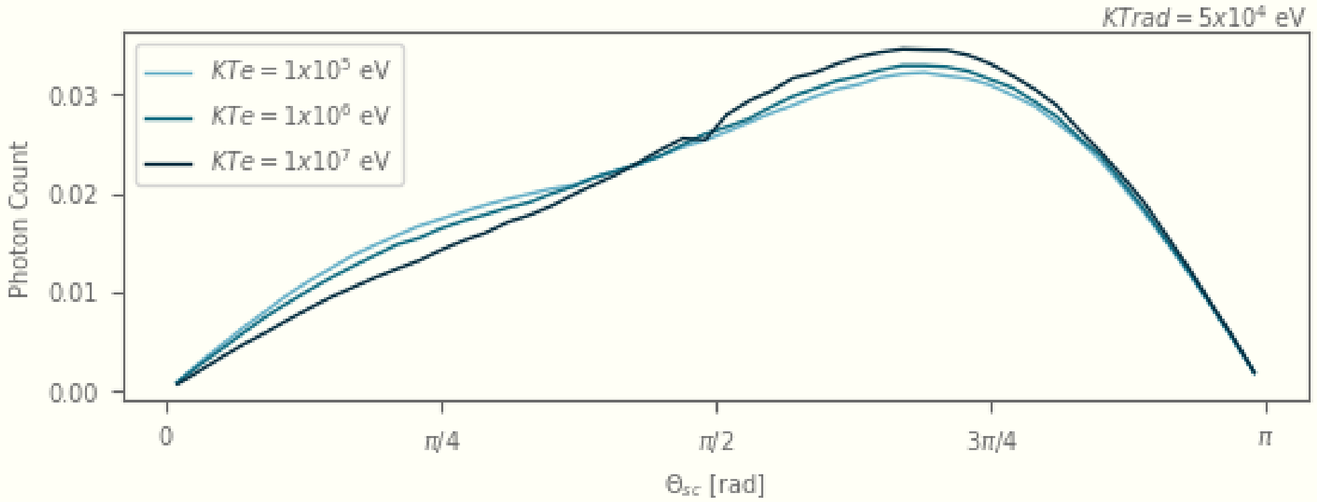
$$\epsilon'_e = \frac{\epsilon_e}{1 + \frac{\epsilon_e}{m_e c^2}(1 - \cos\Theta_{sc})}$$

CALCULATE THE DIRECTION OF THE PHOTON AFTER SCATTERING

$$D'_{e,x} = D_{e,x}\cos\Theta_{sc} + P_i$$

$$D'_{e,y} = D_{e,y}\cos\Theta_{sc} + P$$

$$D'_{e,z} = D_{e,z}\cos\Theta_{sc} + P_t$$



SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

ELECTRON REST

PERFORM COMPTON SCATTERING

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

OBSERVER

RESULTS

CALCULATE THE ENERGY OF THE PHOTON AFTER SCATTERING

$$\epsilon'_e = \frac{\epsilon_e}{1 + \frac{\epsilon_e}{m_e c^2}(1 - \cos\Theta_{sc})}$$

CALCULATE THE DIRECTION OF THE PHOTON AFTER SCATTERING

ANGLE BETWEEN THE POLARIZATION VECTOR OF THE SEED PHOTON AND THE PLANE OF SCATTERING

view for all photons >

$$D'_{e,x} = D_{e,x}\cos\Theta_{sc} + P_{e,x}\sin\Theta_{sc}\cos\Phi_{sc} + \sin\Theta_{sc}\sin\Phi_{sc}\left(D_{e,y}P_{e,z} - D_{e,z}P_{e,y}\right)$$

$$D'_{e,y} = D_{e,y}\cos\Theta_{sc} + P_{e,y}\sin\Theta_{sc}\cos\Phi_{sc} + \sin\Theta_{sc}\sin\Phi_{sc}\left(D_{e,z}P_{e,x} - D_{e,x}P_{e,z}\right)$$

$$D'_{e,z} = D_{e,z}\cos\Theta_{sc} + P_{e,z}\sin\Theta_{sc}\cos\Phi_{sc} + \sin\Theta_{sc}\sin\Phi_{sc}\left(D_{e,x}P_{e,y} - D_{e,y}P_{e,x}\right)$$

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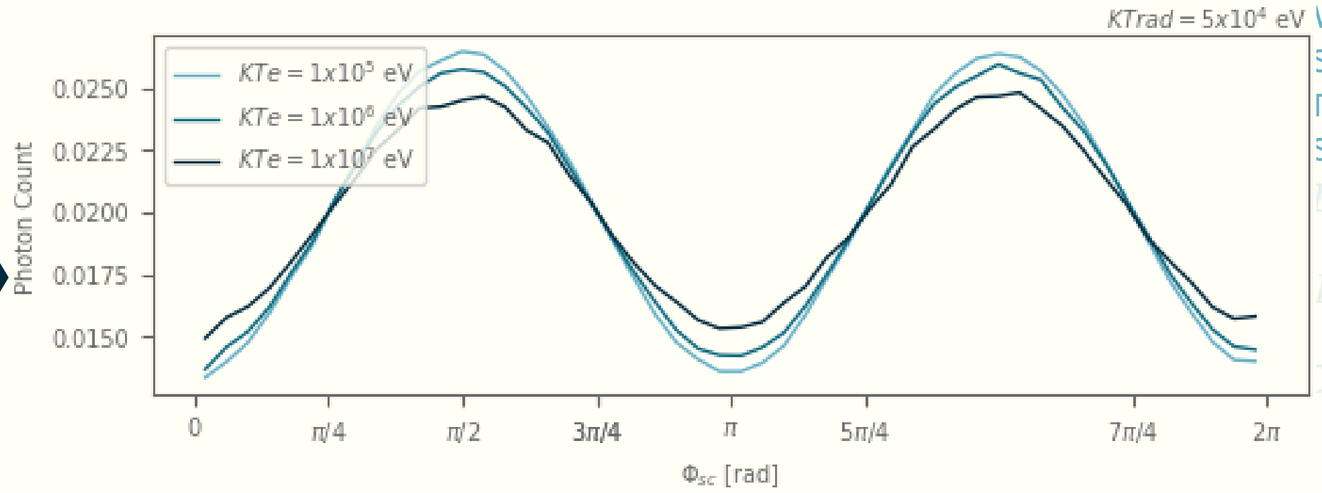
$$\epsilon_e' = \frac{\epsilon_e}{1 + \frac{\epsilon_e}{m_e c^2}(1 - \cos\Theta_{sc})}$$

CALCULATE THE DIRECTION OF THE PHOTON AFTER SCATTERING



ANGLE BETWEEN THE POLARIZATION VECTOR OF THE SEED PHOTON AND THE PLANE OF SCATTERING

$$D_{e,y}P_{e,z} - D_{e,z}P_{e,y})$$

$$D_{e,z}P_{e,x} - D_{e,x}P_{e,z})$$

$$D_{e,x}P_{e,y} - D_{e,y}P_{e,x})$$

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WILL THE PHOTON UNDERGO COMPTON SCATTERING?

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?

CALCULATE THE POLARIZATION VECTOR

$$\vec{P}_{em} = \sin \alpha_r \, \vec{Q}_+ + \cos \alpha_r \, \vec{Q}_-$$

$$\alpha_r \in [0, 2\pi]$$

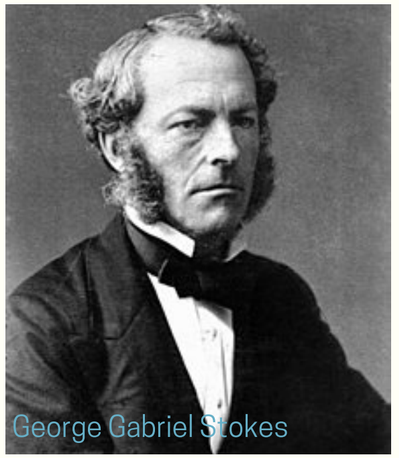
CALCULATE THE CONTRIBUTIONS OF THE PHOTON TO THE STOKES PARAMETERS

$$Q_i = \left(\vec{P}_{em} \cdot \vec{Q}_+\right)^2 - \left(\vec{P}_{em} \cdot \vec{Q}_-\right)^2$$

$$U_i = \left(\vec{P}_{em} \cdot \vec{U}_+\right)^2 - \left(\vec{P}_{em} \cdot \vec{U}_-\right)^2$$

view for all photons >

POLARIZATION SIGNATUTES



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SINGLE PHOTON APPROACH

OBSERVER → **EMISSION** → ELECTRON REST → EMISSION → OBSERVER → RESULTS

GENERATE A SEED PHOTON

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

PERFORM COMPTON SCATTERING

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

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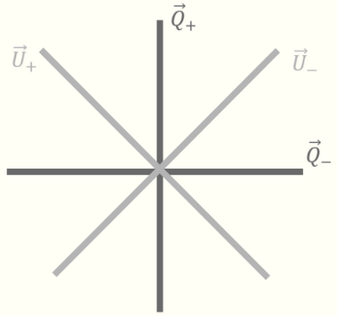
WILL THE PHOTON BE POLARIZED AFTER SCATTERING?



CALCULATE THE CONTRIBUTIONS OF THE PHOTON TO THE STOKES PARAMETERS

$$Q_i = \left(\vec{P}_{em}\cdot\vec{Q}_+\right)^2 - \left(\vec{P}_{em}\cdot\vec{Q}_-\right)^2$$

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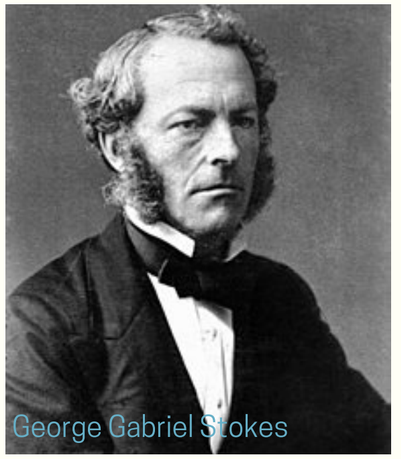
view for all photons >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POLARIZATION SIGNATUTES

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STOKES PARAMETERS ARE ADDITIVE

$$Q = \sum_{i=0}^{N_{phot}} Q_i$$

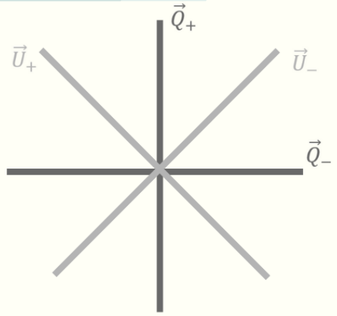
$$U = \sum_{i=0}^{N_{phot}} U_i$$

POLARIZATION SIGNATUTES

BINNED IN THE VIEWING ANGLE AND PHOTON ENERGIES

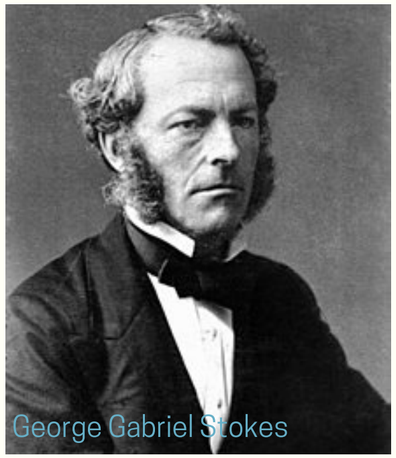
WILL THE PHOTON UNDERGO COMPTON SCATTERING?

WILL THE PHOTON BE POLARIZED AFTER SCATTERING?



$$\Pi = \frac{\sqrt{Q^2 + U^2}}{N_{phot}}$$

$$\chi = \frac{1}{2}\tan^{-1}\frac{U}{Q}$$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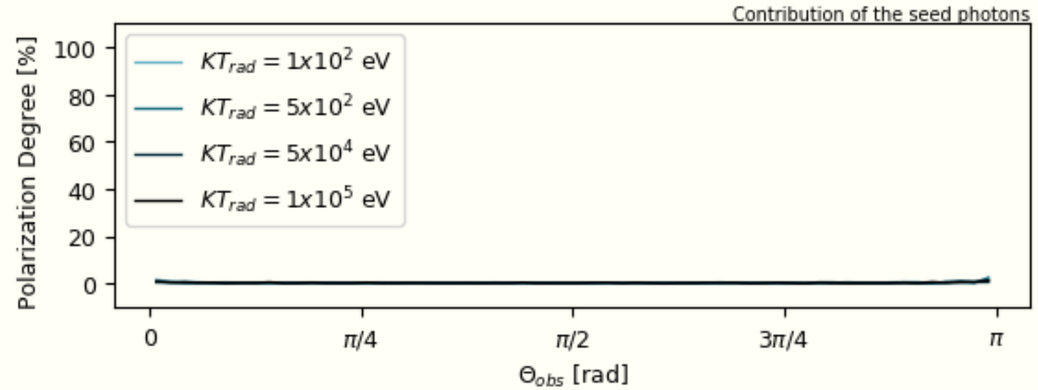

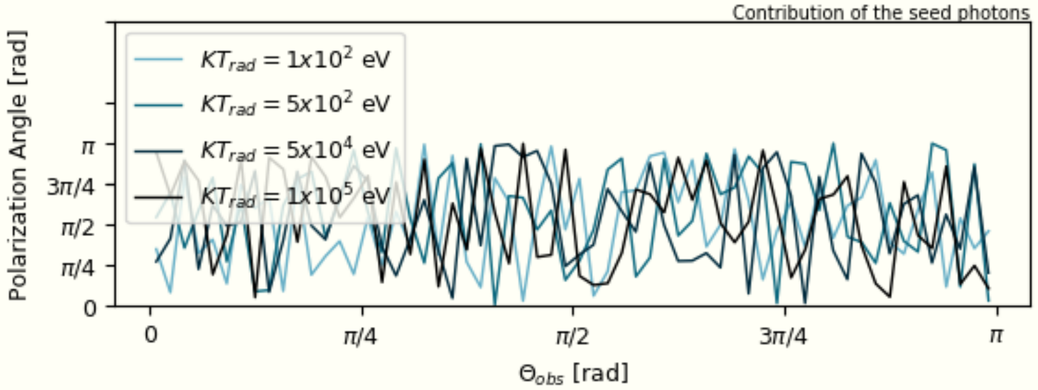

SINGLE PHOTON APPROACH

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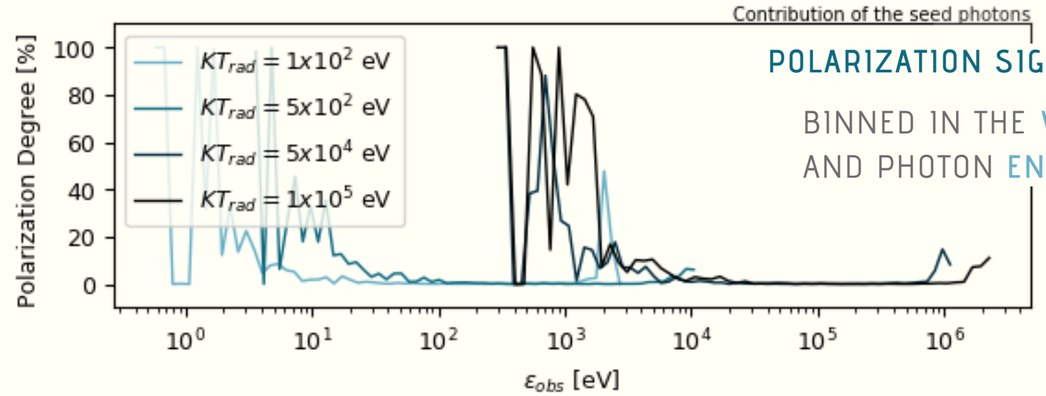
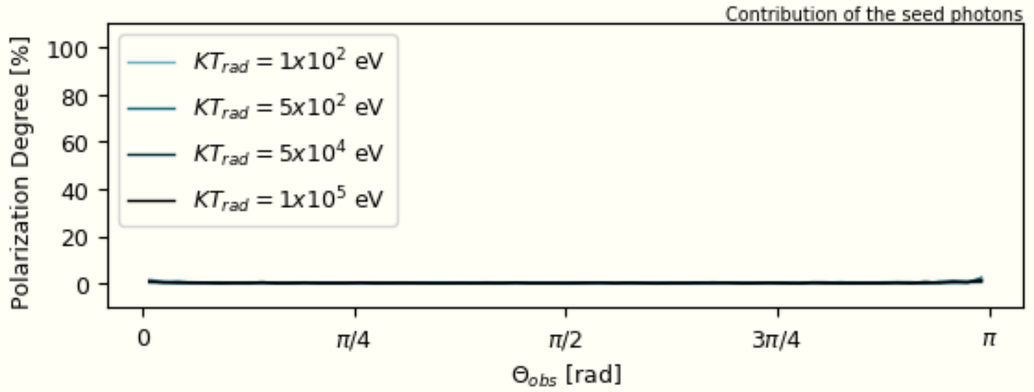
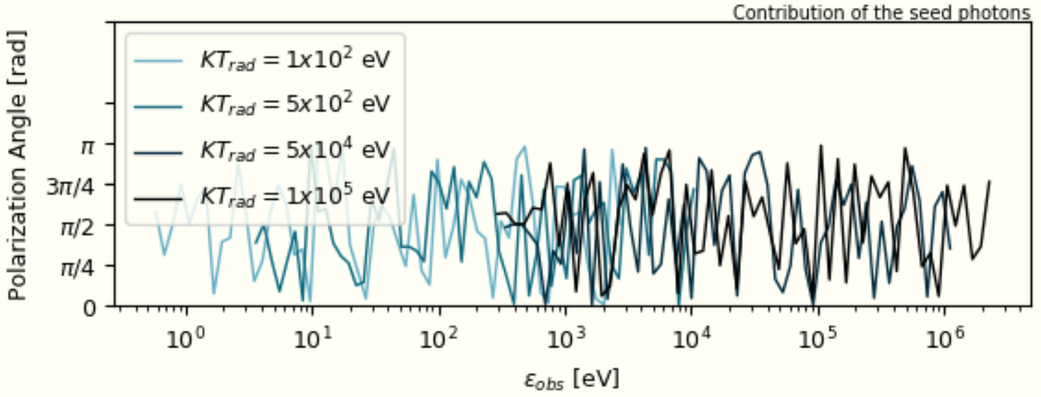
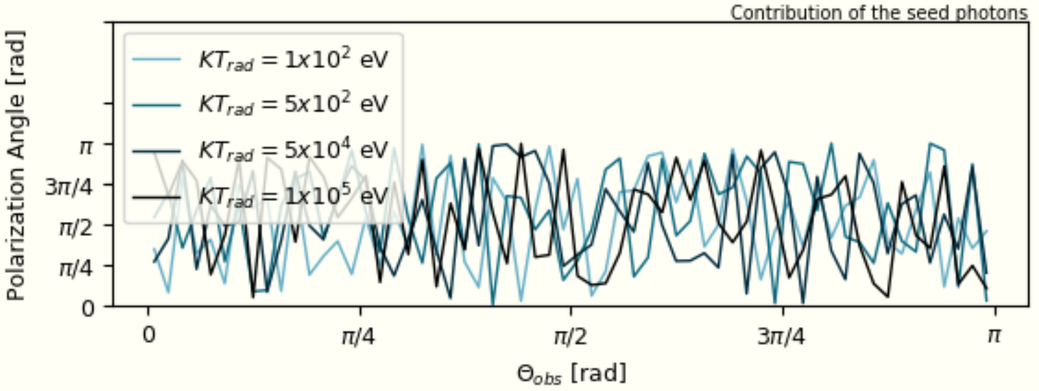








SINGLE PHOTON APPROACH

OBSERVER → EMISSION → GENERATE A SEED PHOTON → CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING → DRAW AN ELECTRON → ELECTRON REST → PERFORM COMPTON SCATTERING → EMISSION → CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING → OBSERVER → RESULTS

CALCULATE THE POLARIZATION VECTOR

UNPOLARIZED

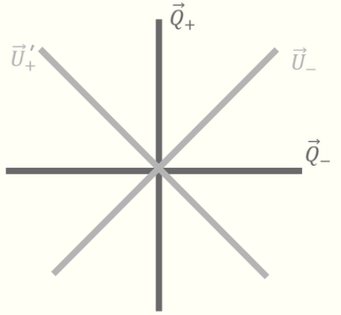
$$\vec{P}'_{em} = \sin\alpha_r\,\vec{Q}'_{+} + \cos\alpha_r\,\vec{Q}'_{-}$$

$$\alpha_r \in [0,2\pi]$$

POLARIZED

$$\vec{P}'_{em} = \frac{1}{\vec{P}'_{em}}\left(\vec{P}'_{em}\times\vec{D}'_{em}\right)\times\vec{D}'_{em}$$

Matt *et al*, 1995



CALCULATE THE CONTRIBUTIONS OF THE PHOTON TO THE STOKES PARAMETERS

$$Q'_i = \left(\vec{P}_{em}\cdot\vec{Q}'_{+}\right)^2 - \left(\vec{P}_{em}\cdot\vec{Q}'_{-}\right)^2$$

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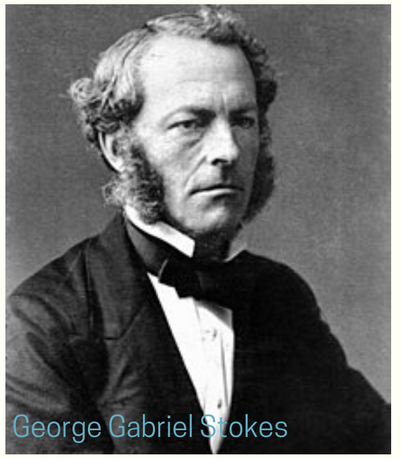
view for all photons >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POLARIZATION SIGNATUTES

SINGLE PHOTON APPROACH

OBSERVER → EMISSION → GENERATE A SEED PHOTON → CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING → DRAW AN ELECTRON → ELECTRON REST → PERFORM COMPTON SCATTERING → EMISSION → CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING → OBSERVER → RESULTS

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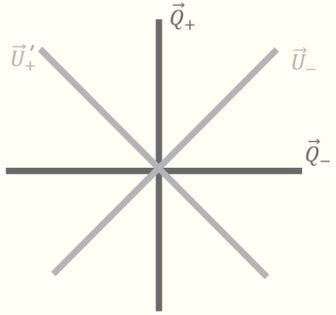
Matt *et al*, 1995



CALCULATE THE CONTRIBUTIONS OF THE PHOTON TO THE STOKES PARAMETERS

$$Q' = \left(\vec{P}_{em} \cdot \vec{Q}_+\right)^2 - \left(\vec{P}_{em} \cdot \vec{Q}_-\right)^2$$

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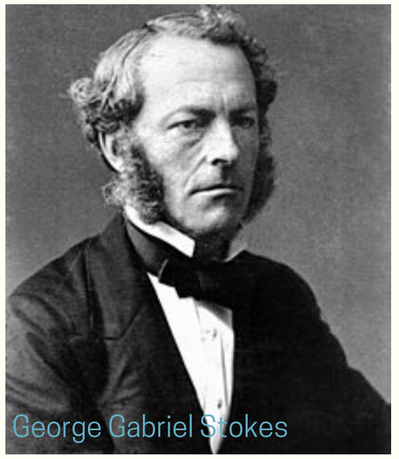
view for all photons >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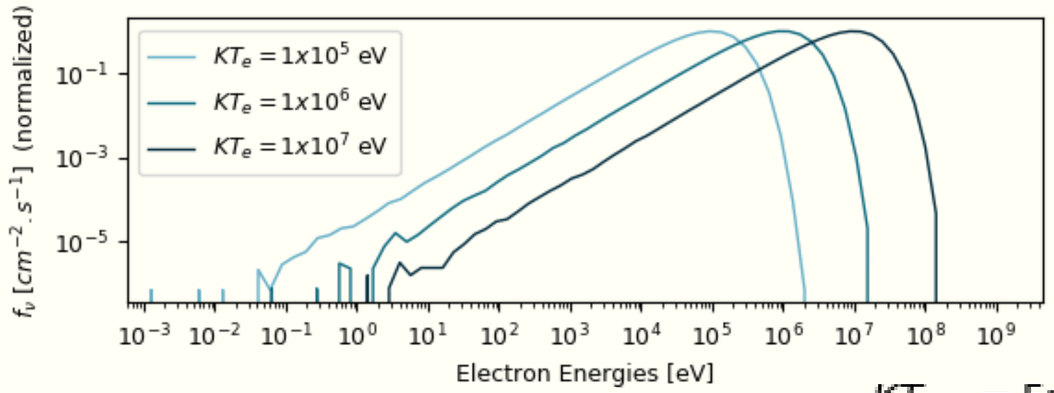
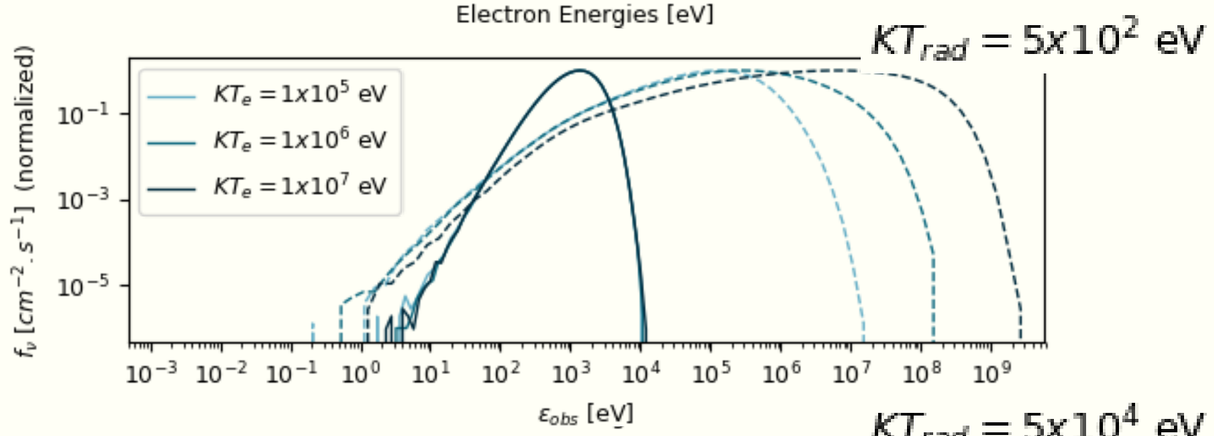
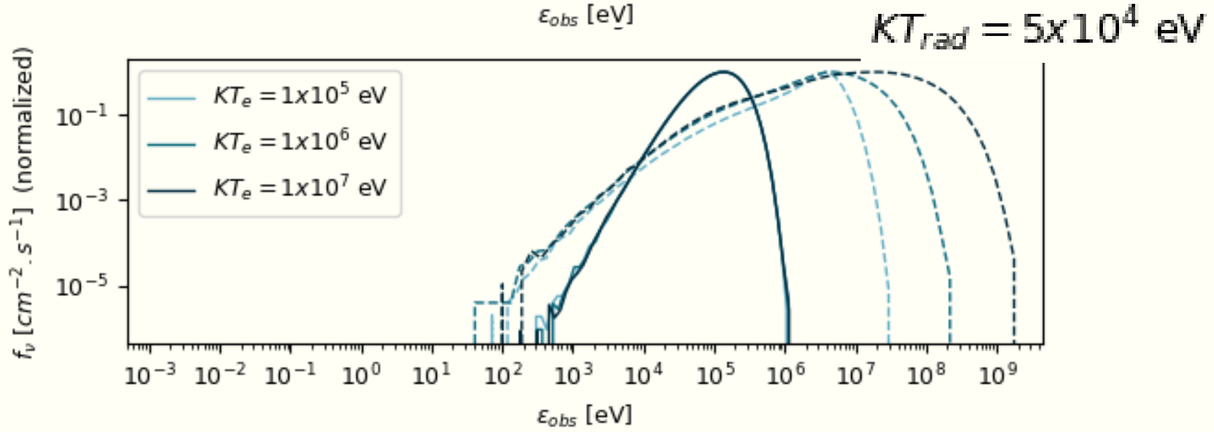
SPECTRAL ENERGY DISTRIBUTIONS



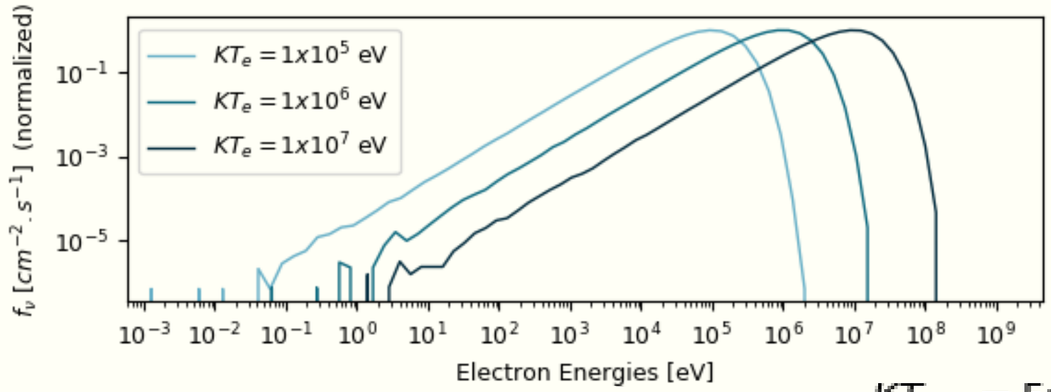
PHOTON ENERGIES SHIFT TO HIGHER ENERGIES

why?

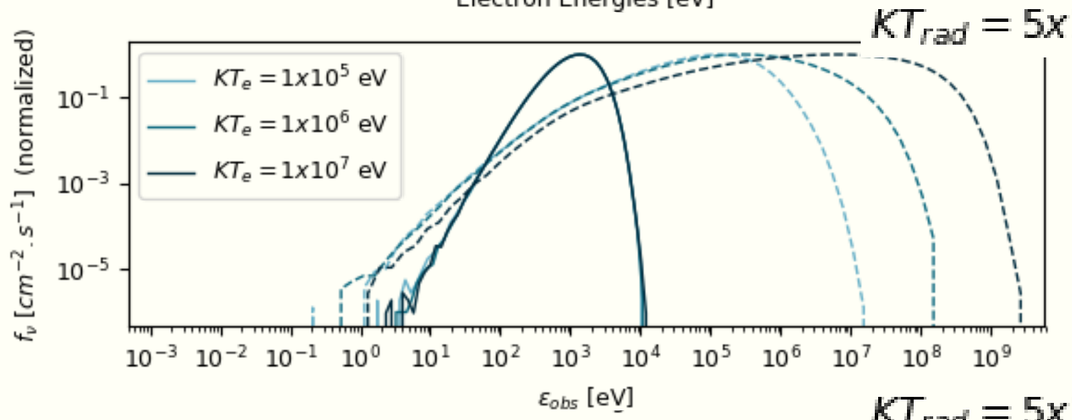


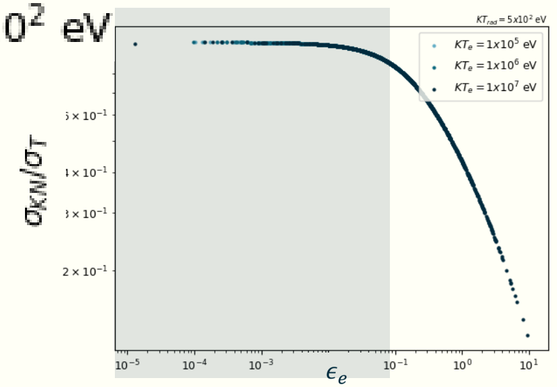


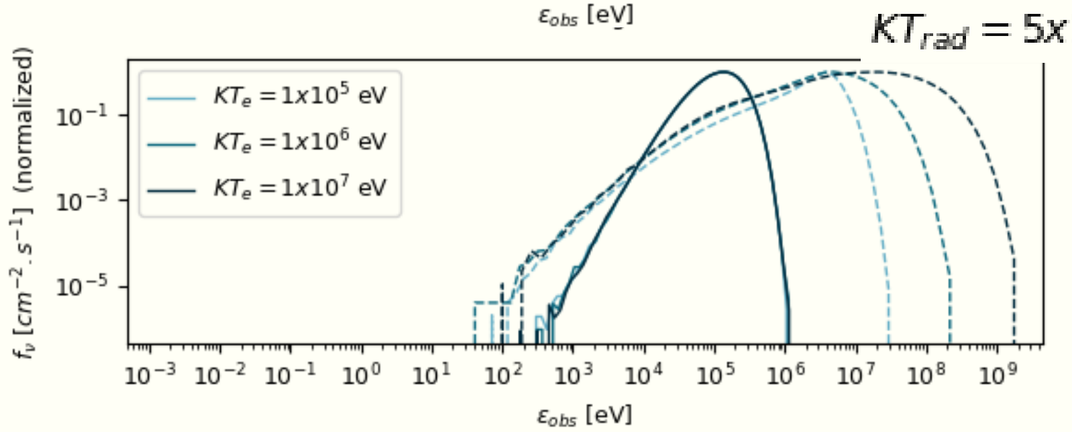
SPECTRAL ENERGY DISTRIBUTIONS

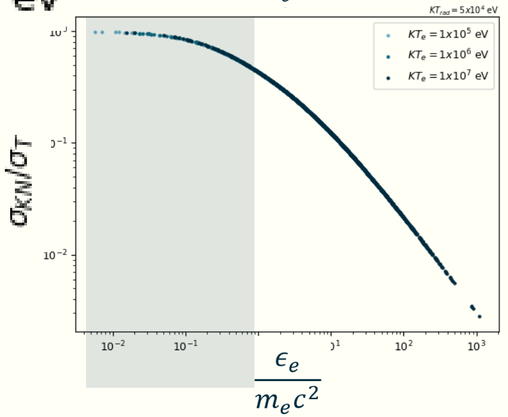


PHOTON ENERGIES SHIFT TO HIGHER ENERGIES









POLARIZATION SIGNAL

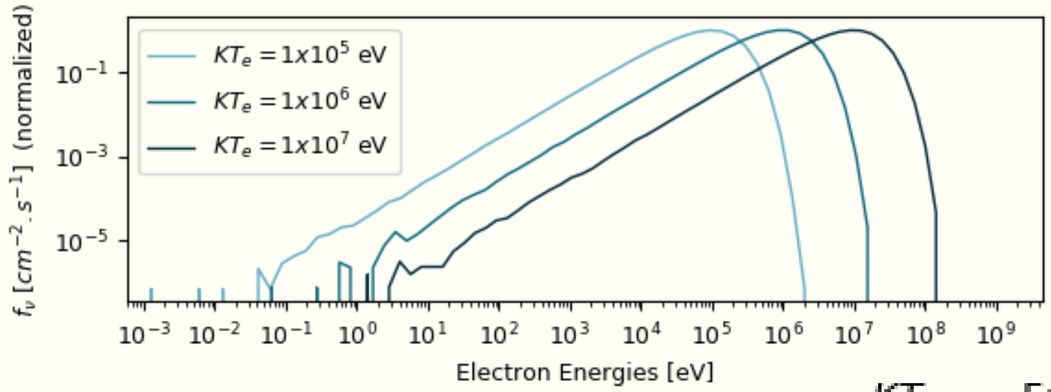
$$\frac{\epsilon_e}{m_e c^2} \ll 1 \rightarrow$$ THOMSON REGIME

$$\epsilon'_e \sim \epsilon_e$$

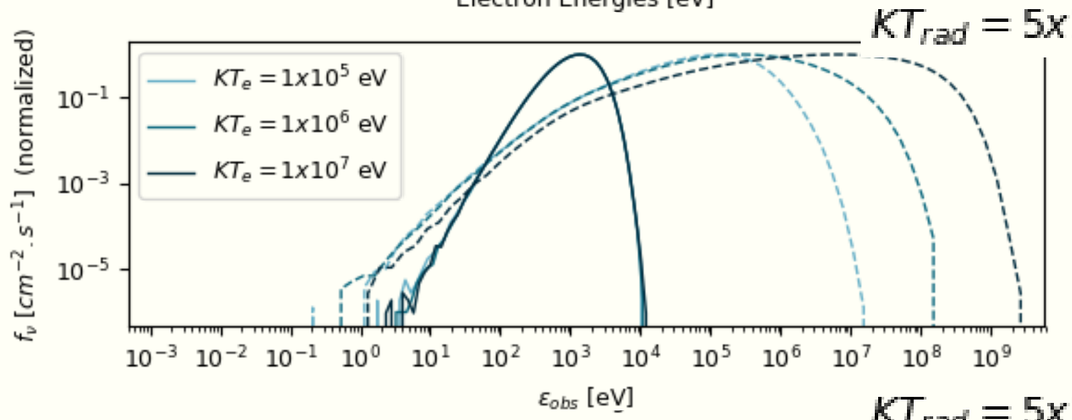
$$\frac{\epsilon_e}{m_e c^2} \gg 1 \rightarrow$$ KLEIN NISHINA LIMIT

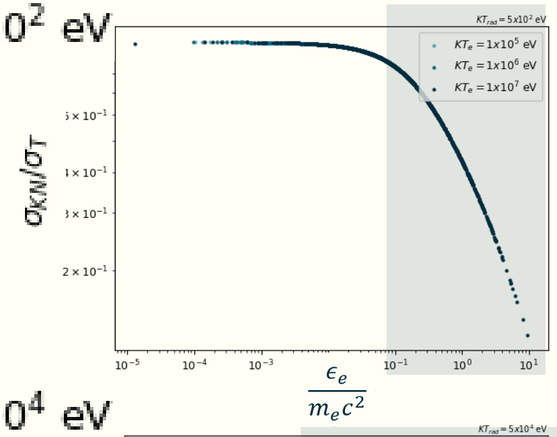
$$\epsilon'_e \sim 1$$

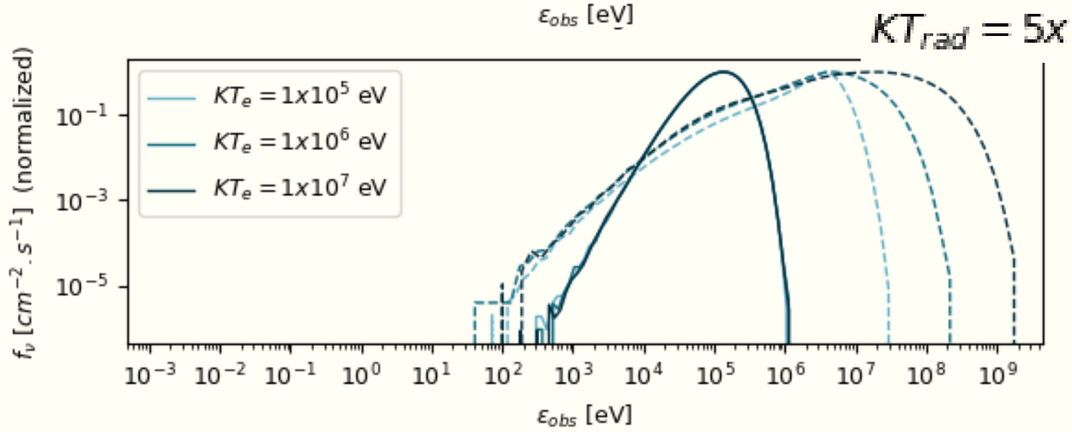
SPECTRAL ENERGY DISTRIBUTIONS

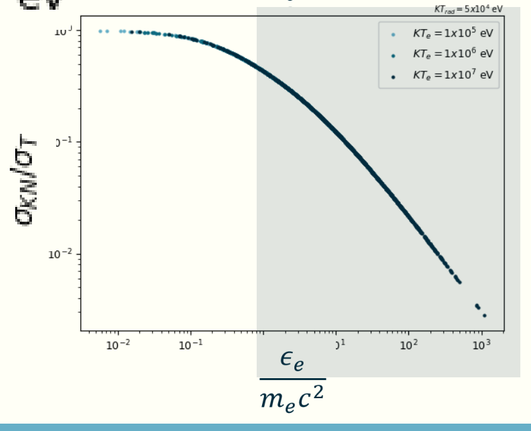


PHOTON ENERGIES SHIFT TO HIGHER ENERGIES









POLARIZATION SIGNAL

$$\frac{\epsilon_e}{m_e c^2} \ll 1 \rightarrow$$ THOMSON REGIME

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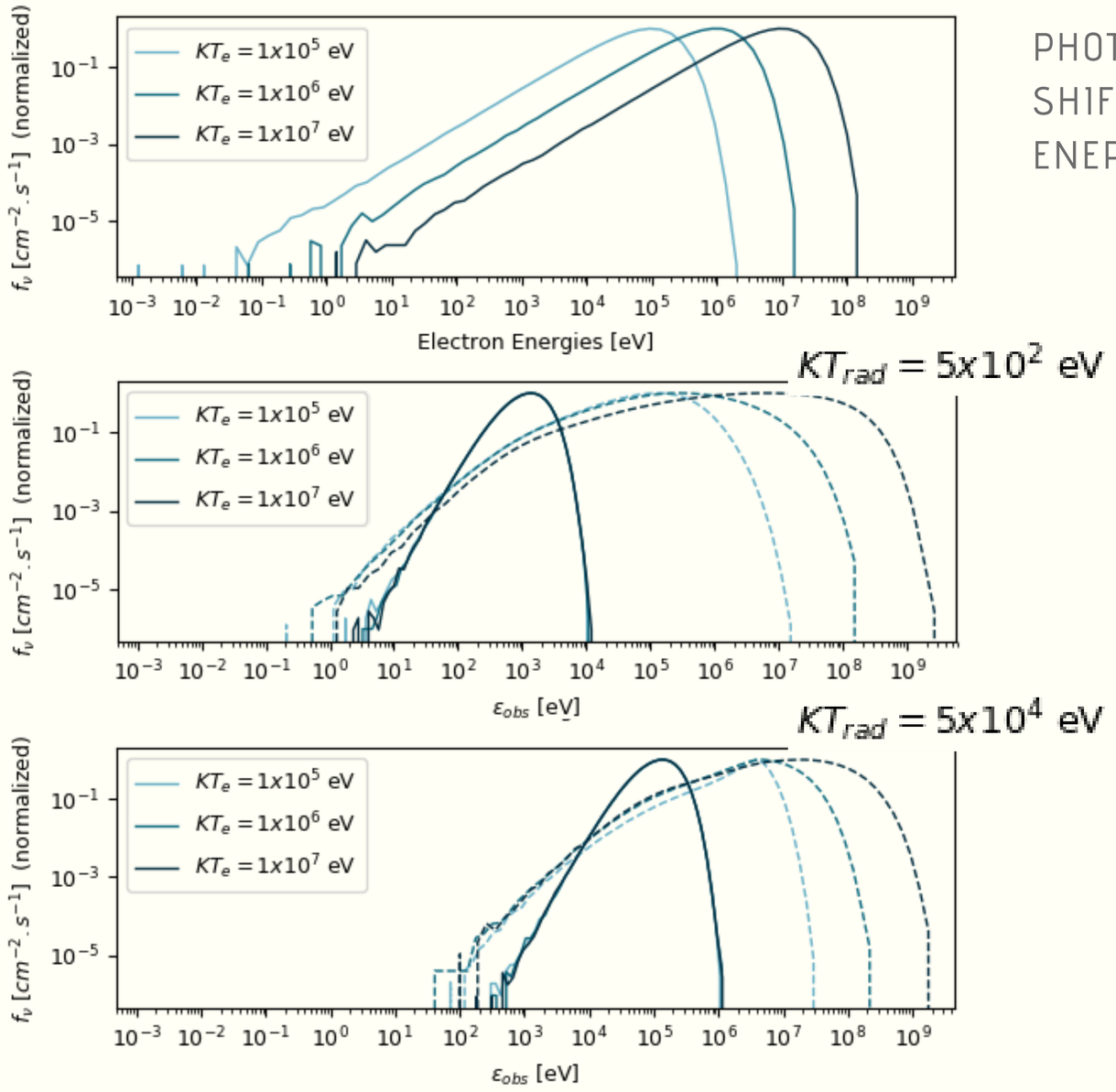
$$\epsilon'_e \sim 1$$

SPECTRAL ENERGY DISTRIBUTIONS

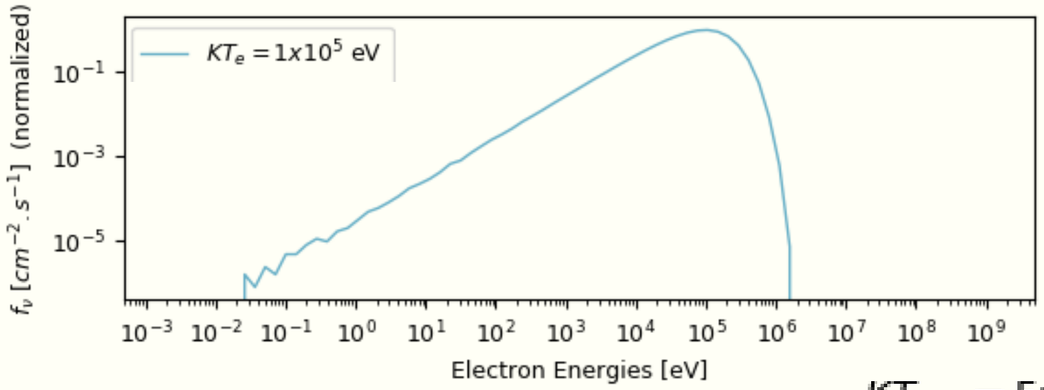


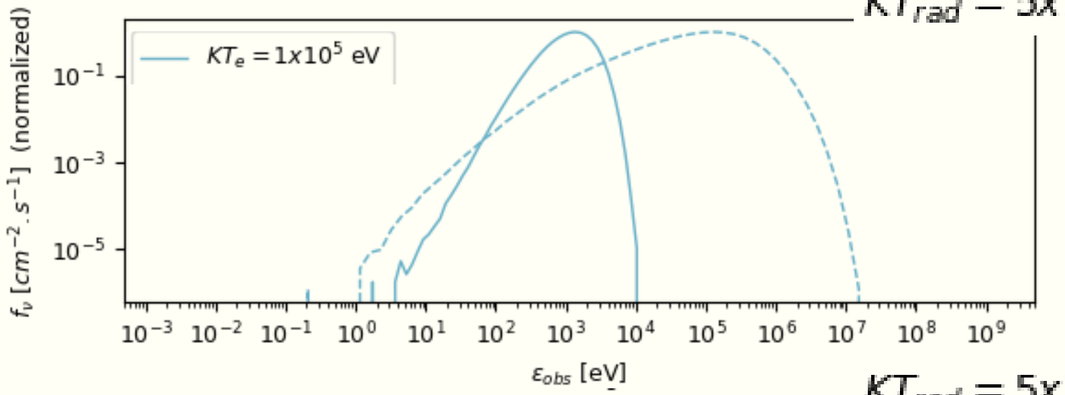
PHOTON ENERGIES SHIFT TO HIGHER ENERGIES

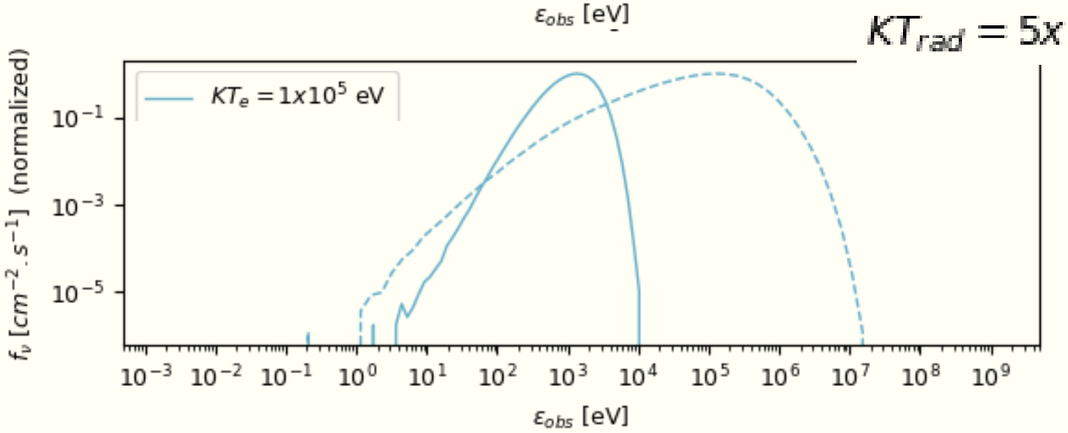
$$\epsilon'_{obs} \sim \Gamma^2 \gamma^2 \epsilon_{obs}$$

SCATTERED PHOTON ENERGIES INCREASE WITH THE INCREASE OF THERMAL TEMPERATURES

SPECTRAL ENERGY DISTRIBUTIONS







PHOTON ENERGIES SHIFT TO HIGHER ENERGIES

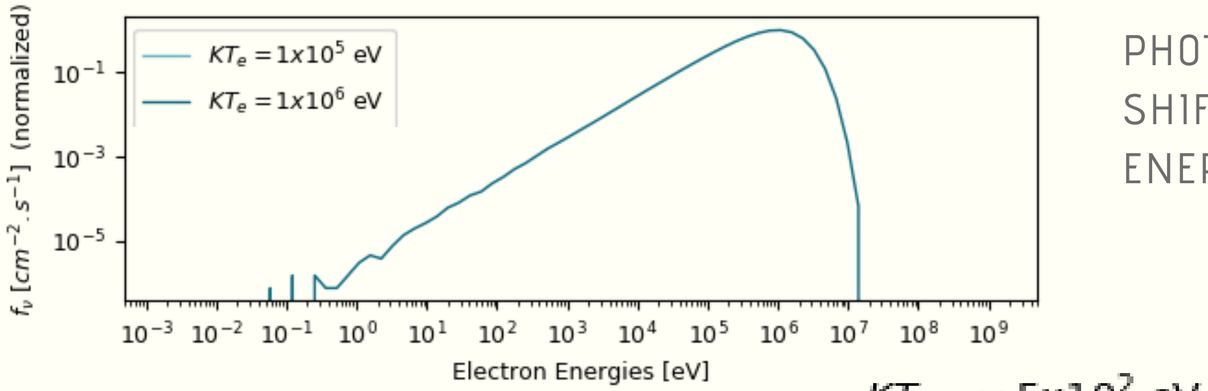
$$\epsilon'_{obs} \sim \Gamma^2 \gamma^2 \epsilon_{obs}$$

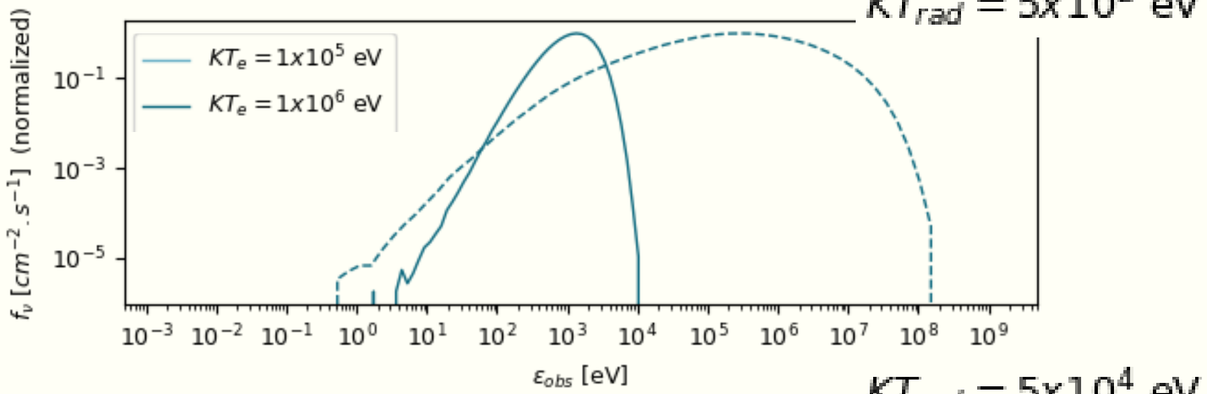
SCATTERED PHOTON ENERGIES **INCREASE** WITH THE INCREASE OF THERMAL TEMPERATURES

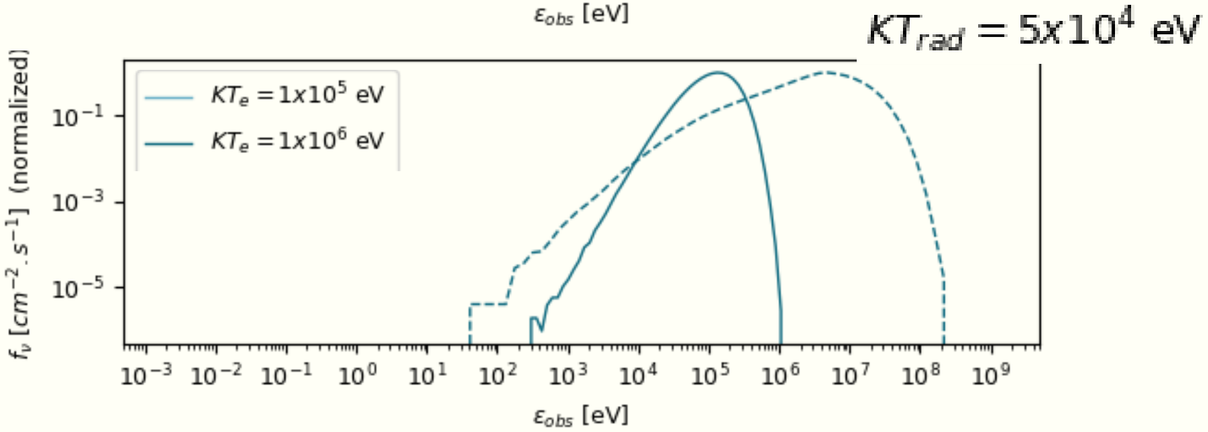
$\frac{\epsilon_e}{m_e c^2}$

SPECTRAL ENERGY DISTRIBUTIONS

POLARIZATION SIGNAL







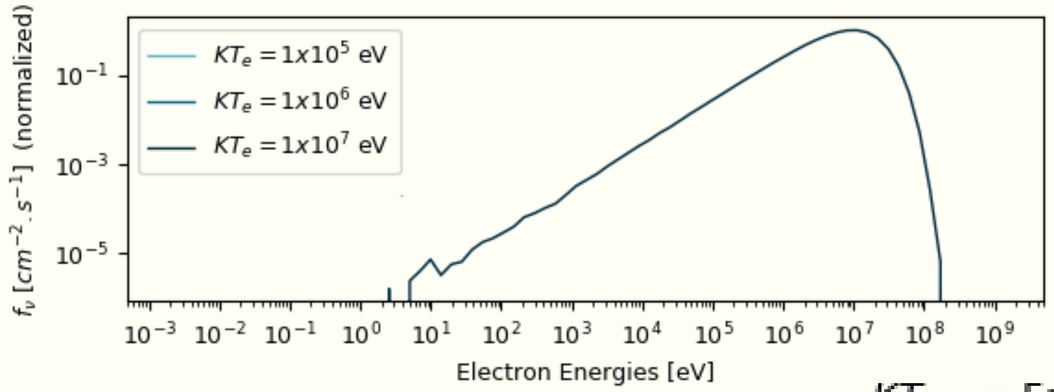
PHOTON ENERGIES SHIFT TO HIGHER ENERGIES

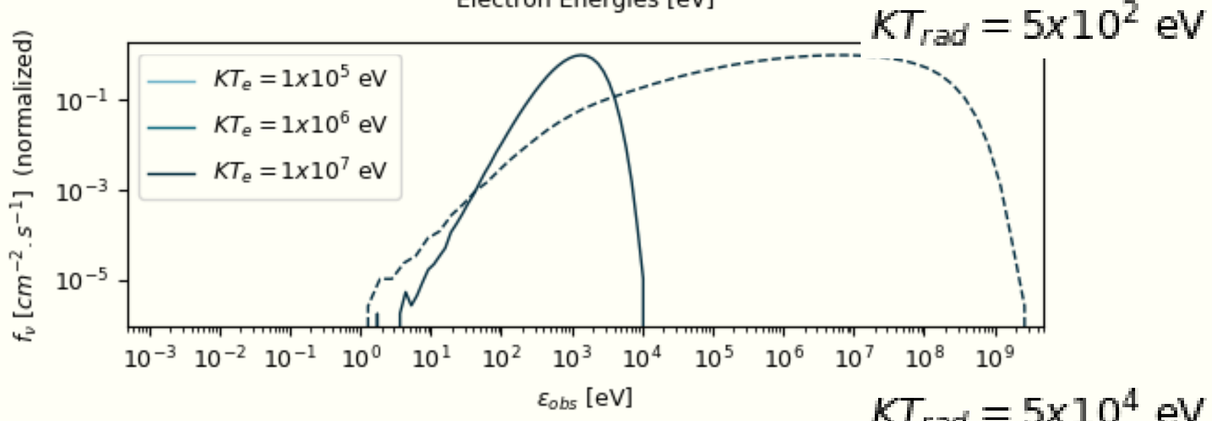
$$\epsilon'_{obs} \sim \Gamma^2 \gamma^2 \epsilon_{obs}$$

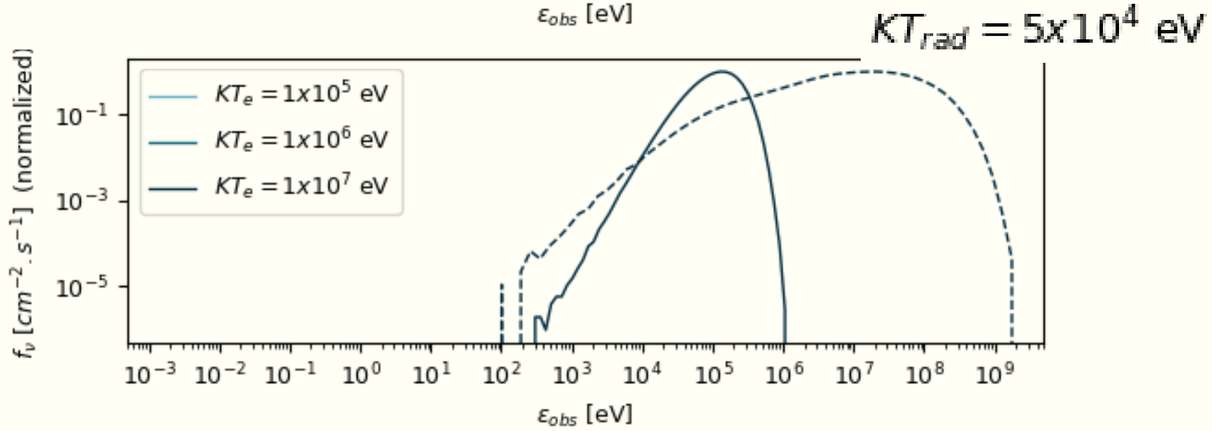
SCATTERED PHOTON ENERGIES **INCREASE** WITH THE **INCREASE OF THERMAL TEMPERATURES**

SPECTRAL ENERGY DISTRIBUTIONS

POLARIZATION SIGNAL







PHOTON ENERGIES SHIFT TO HIGHER ENERGIES

$$\epsilon'_{obs} \sim \Gamma^2 \gamma^2 \epsilon_{obs}$$

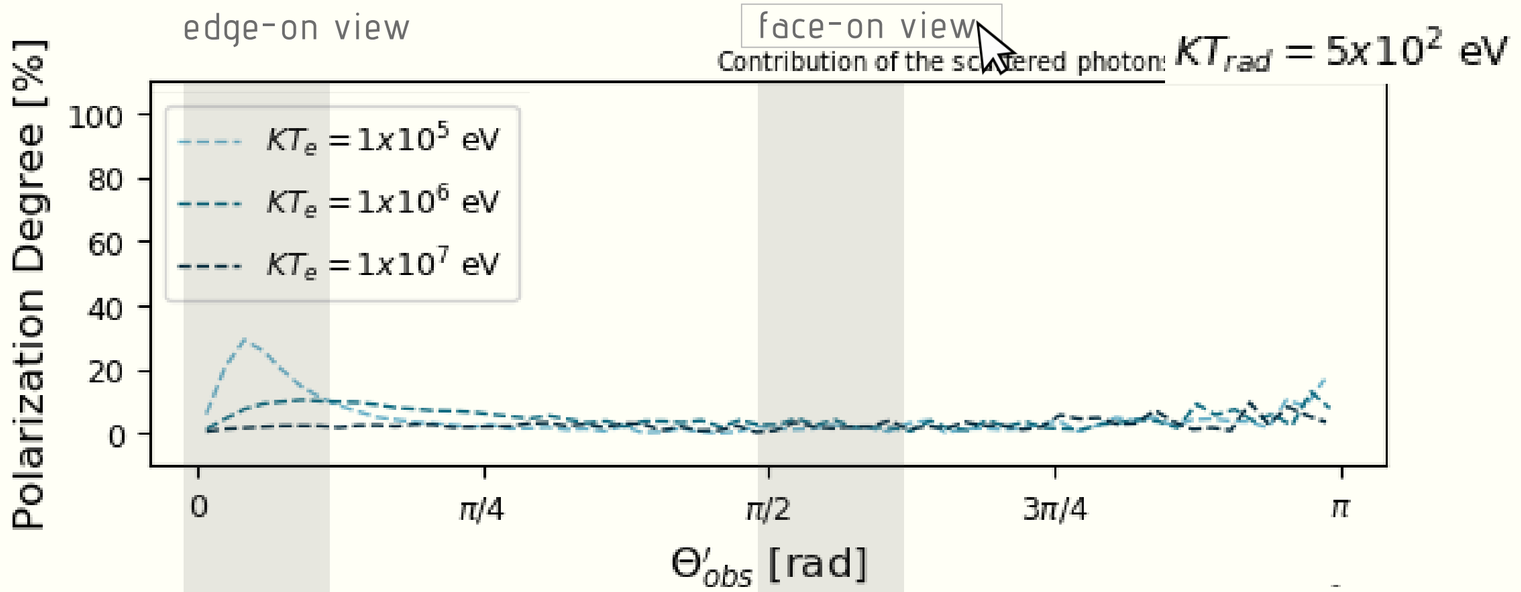
SCATTERED PHOTON ENERGIES **INCREASE** WITH THE INCREASE OF THERMAL TEMPERATURES

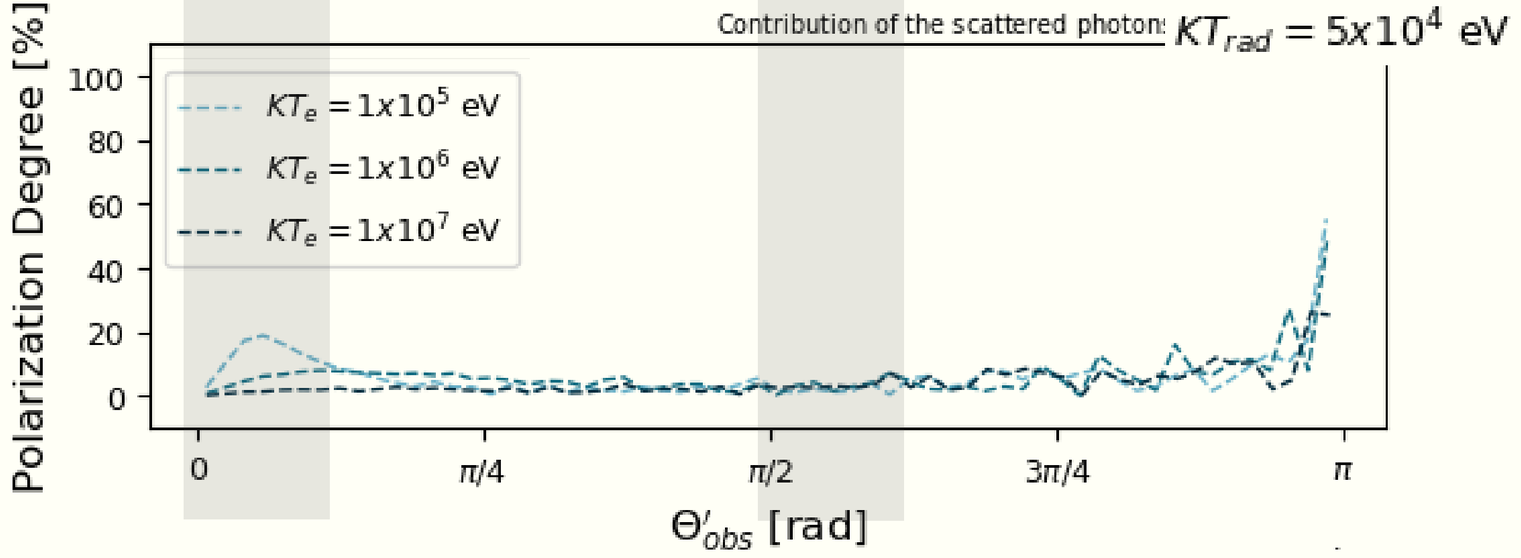
POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

edge-on view face-on view



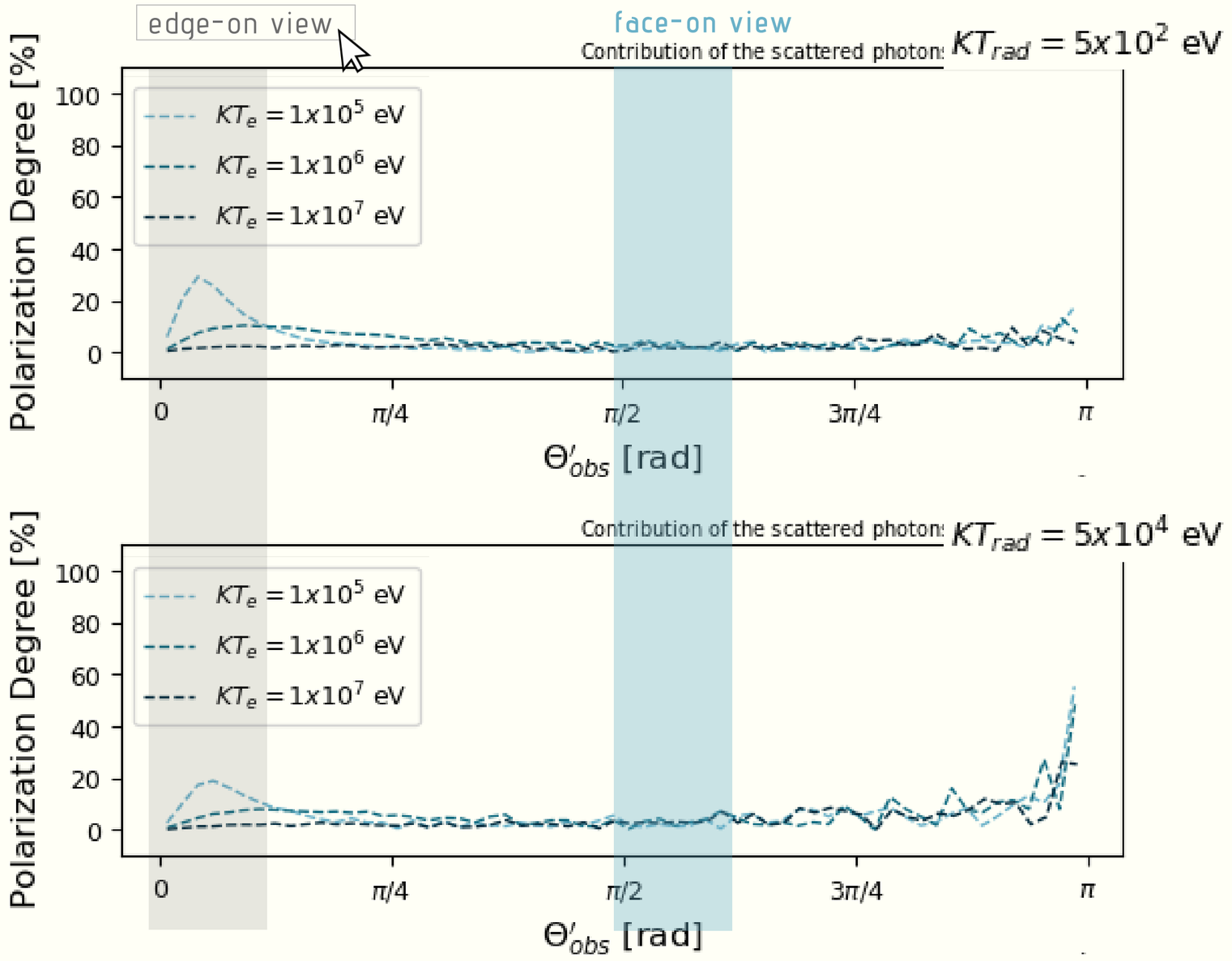


POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

shows at which angle is the polarization degree at the maximum and how the polarization angle changes as a function of the viewing angle



POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

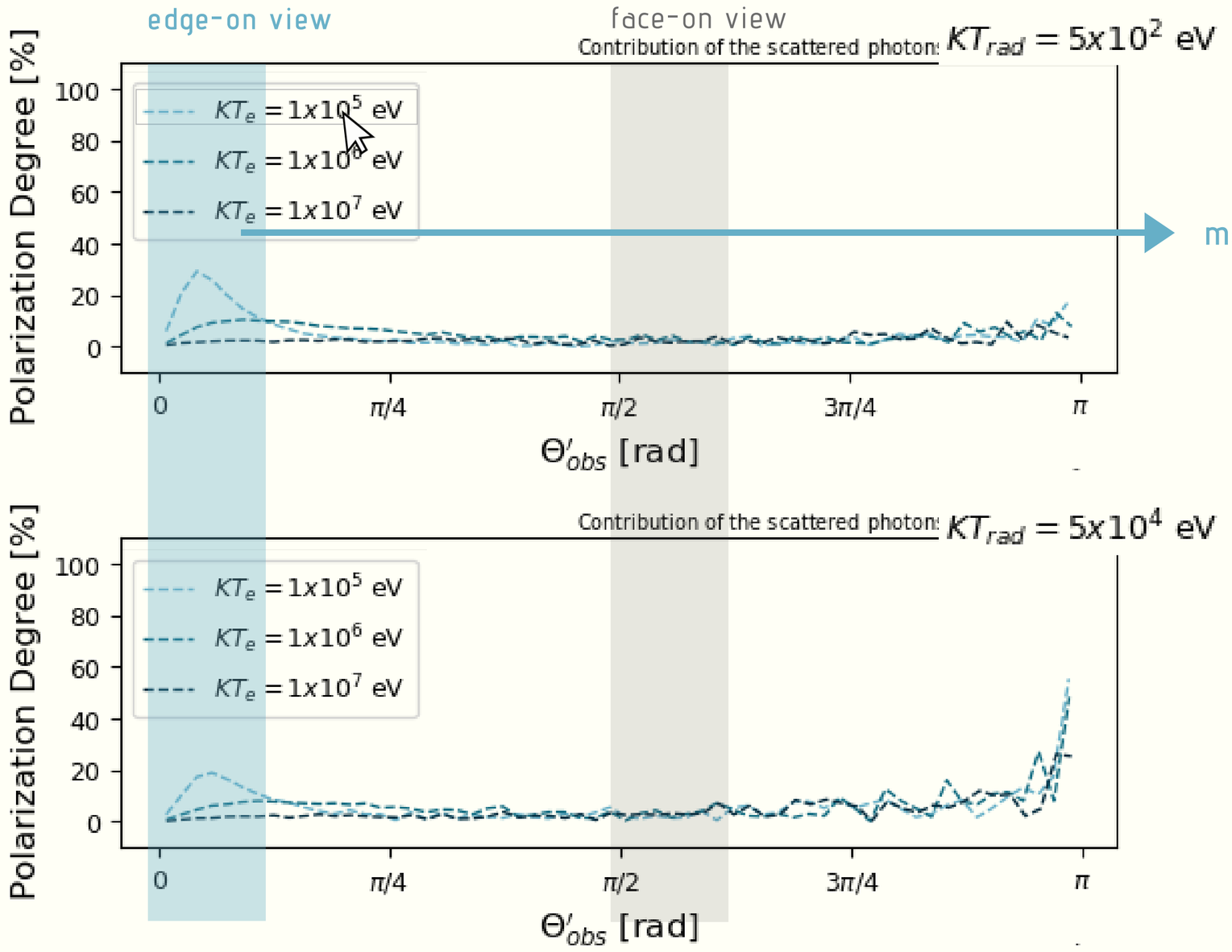
BINNED IN ENERGY

shows at which angle is the polarization degree at the maximum and how the polarization angle changes as a function of the viewing angle

POLARIZATION SIGNAL

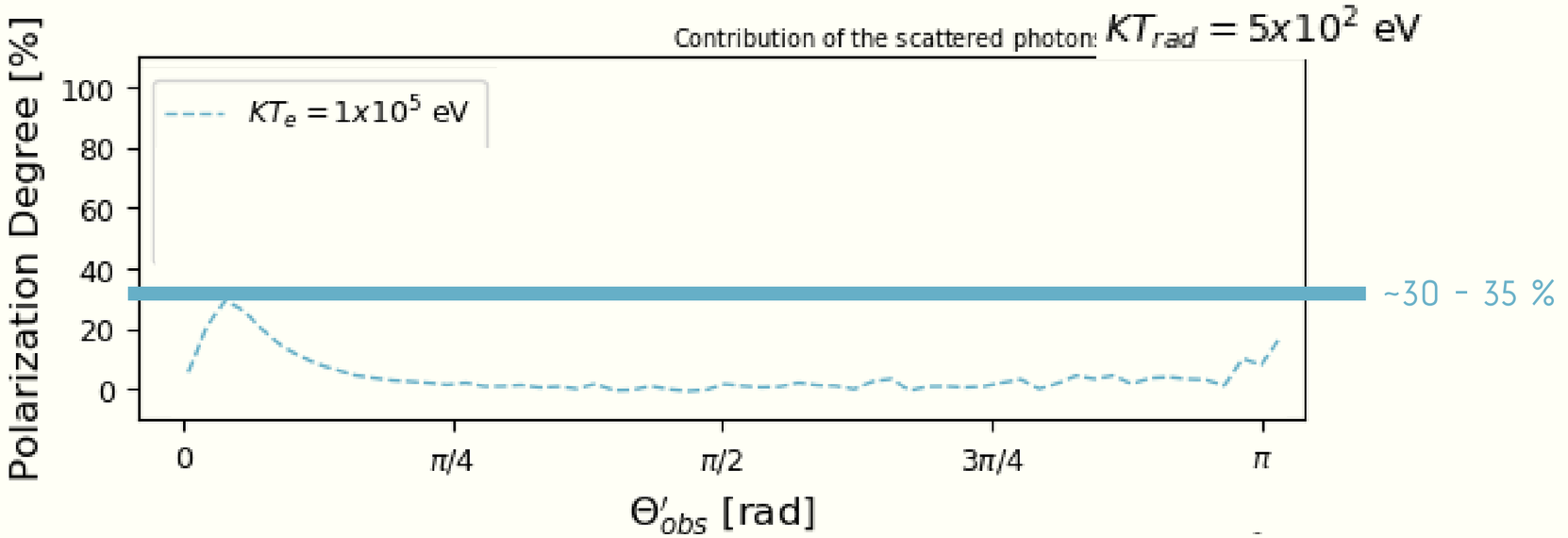
BINNED IN VIEWING ANGLE

BINNED IN ENERGY

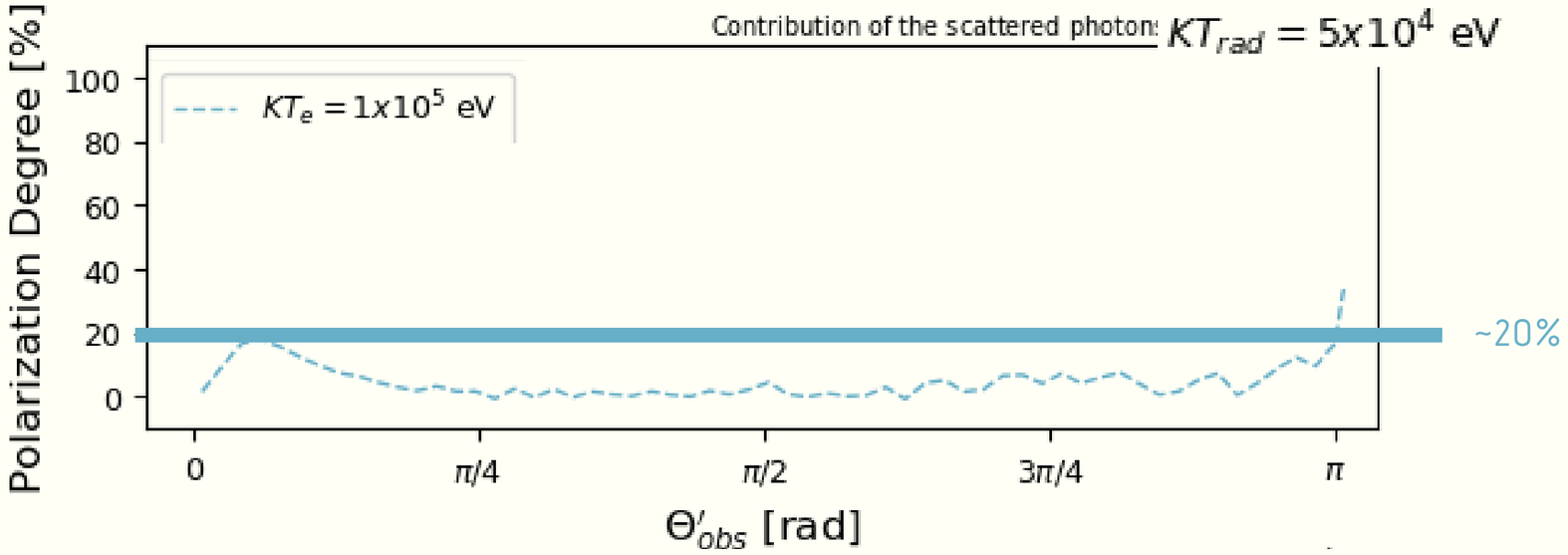


maximum polarization

shows at which angle is the polarization degree at the maximum and how the polarization angle changes as a function of the viewing angle



~30 - 35 %



~20%

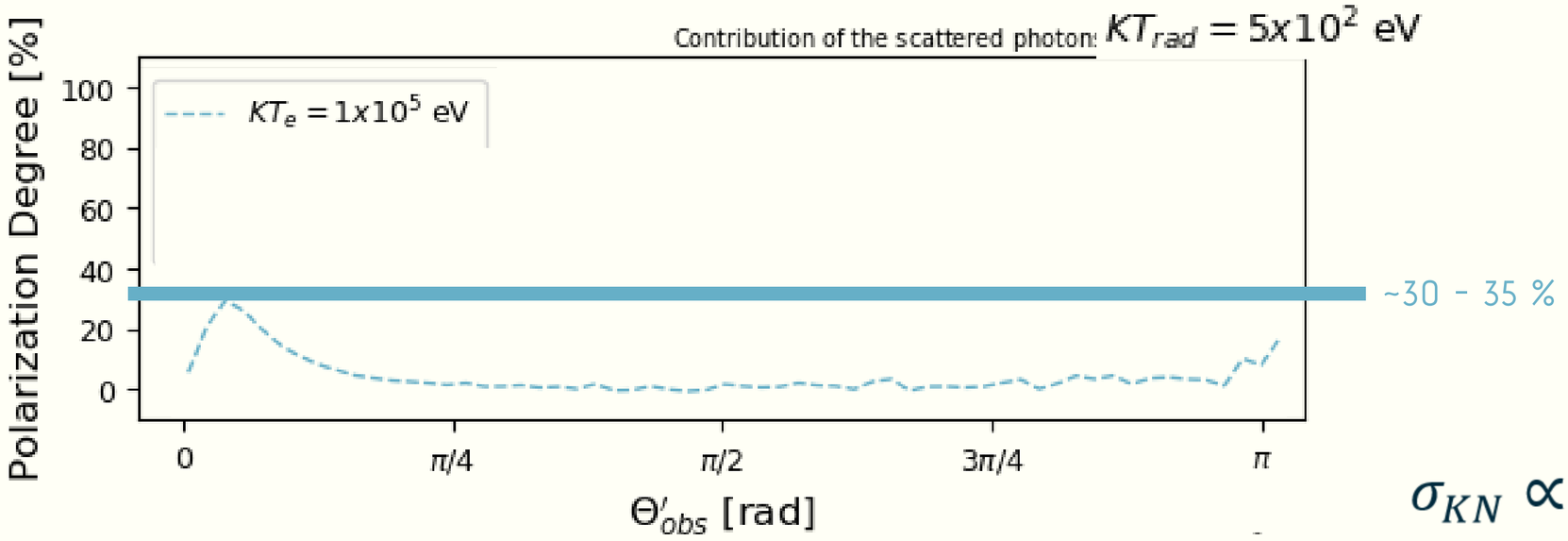
POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

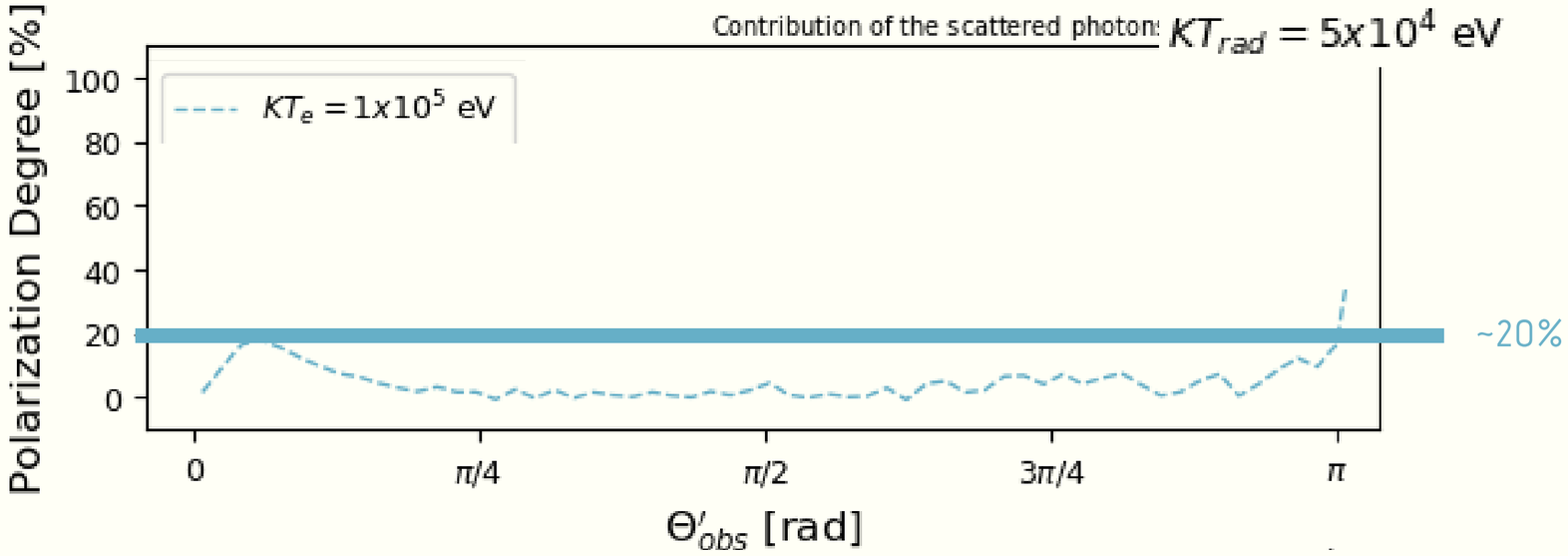
BINNED IN ENERGY

POLARIZATION DEGREES DECREASE WITH THE INCREASE OF PHOTON TEMPERATURES

why?



~30 - 35 %



~20%

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

POLARIZATION DEGREES DECREASE WITH THE INCREASE OF PHOTON TEMPERATURES

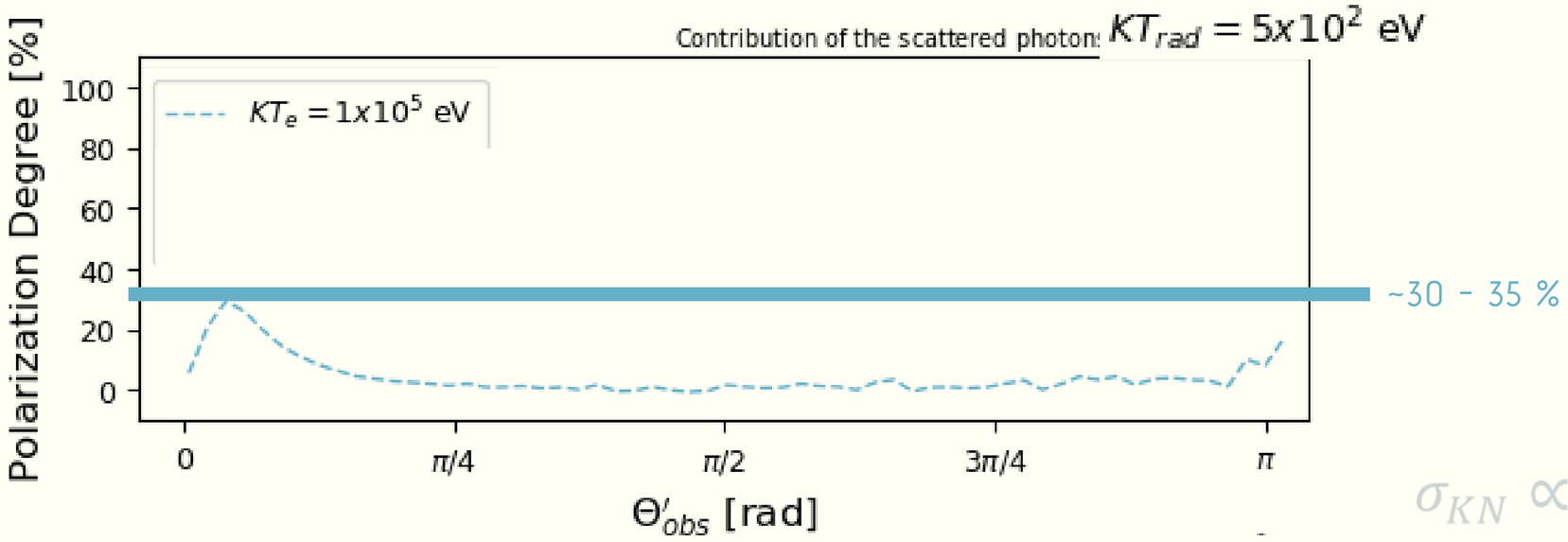
$$\sigma_{KN} \propto \left(\frac{\epsilon'_e}{\epsilon_e} + \frac{\epsilon_e}{\epsilon'_e}\right) - 2 + 4\left(\vec{P}_e \cdot \vec{P}_e{}'\right)$$

$\frac{\epsilon_e}{m_e c^2} \ll 1 \rightarrow$ THOMSON REGIME

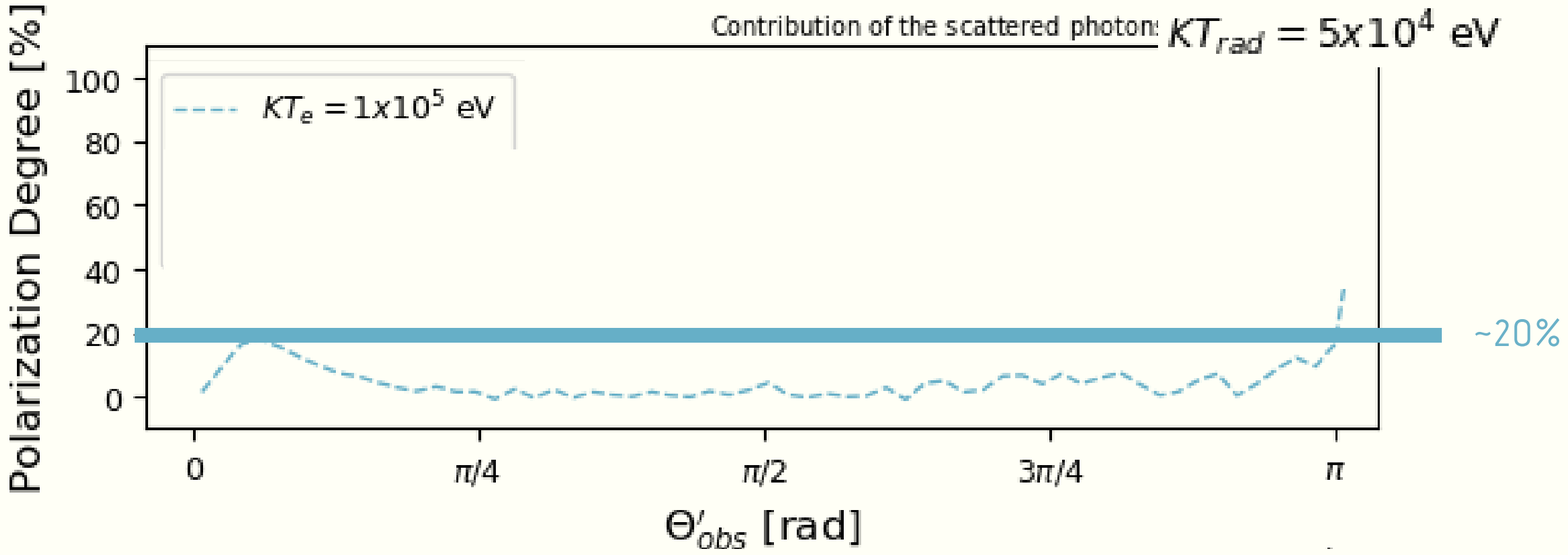
$\epsilon'_e \sim \epsilon_e$

$\frac{\epsilon_e}{m_e c^2} \gg 1 \rightarrow$ KLEIN NISHINA LIMIT

$\epsilon'_e \sim 1$



~30 - 35 %



~20%

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

POLARIZATION DEGREES DECREASE WITH THE INCREASE OF PHOTON TEMPERATURES

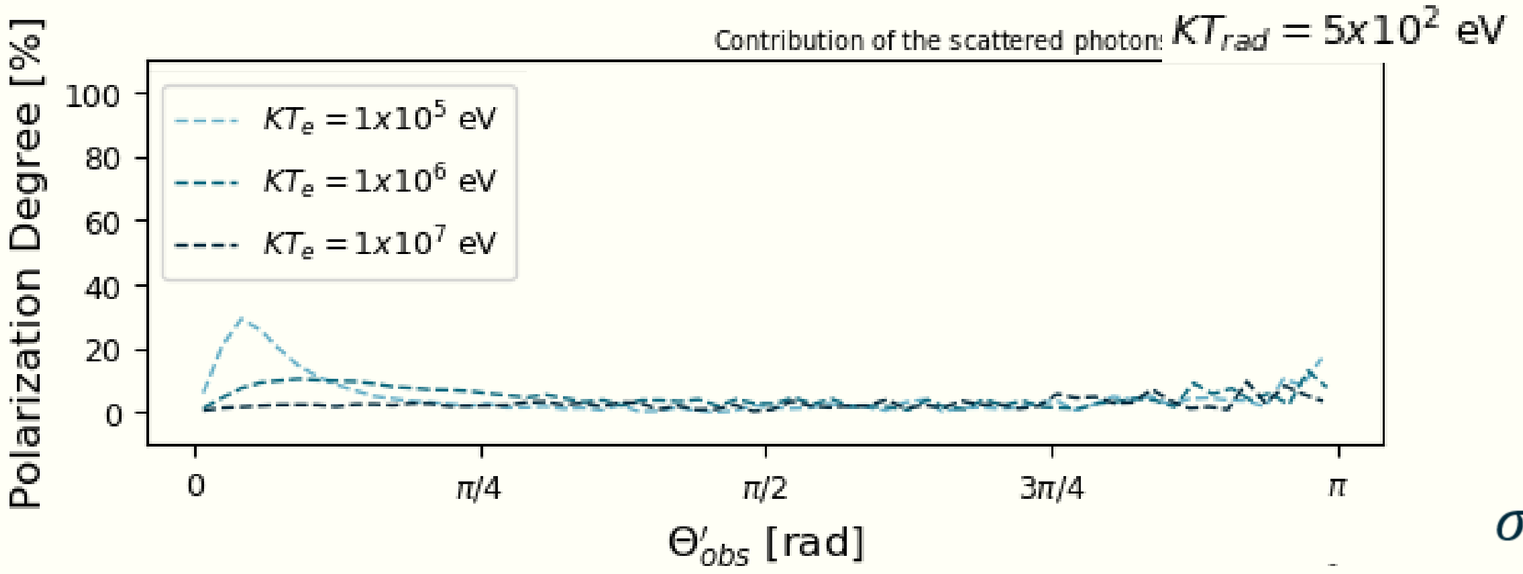
$$\sigma_{KN} \propto \left(\frac{\epsilon'_e}{\epsilon_e} + \frac{\epsilon_e}{\epsilon'_e}\right) - 2 + 4\left(\vec{P}_e \cdot \vec{P}_e{}'\right)$$

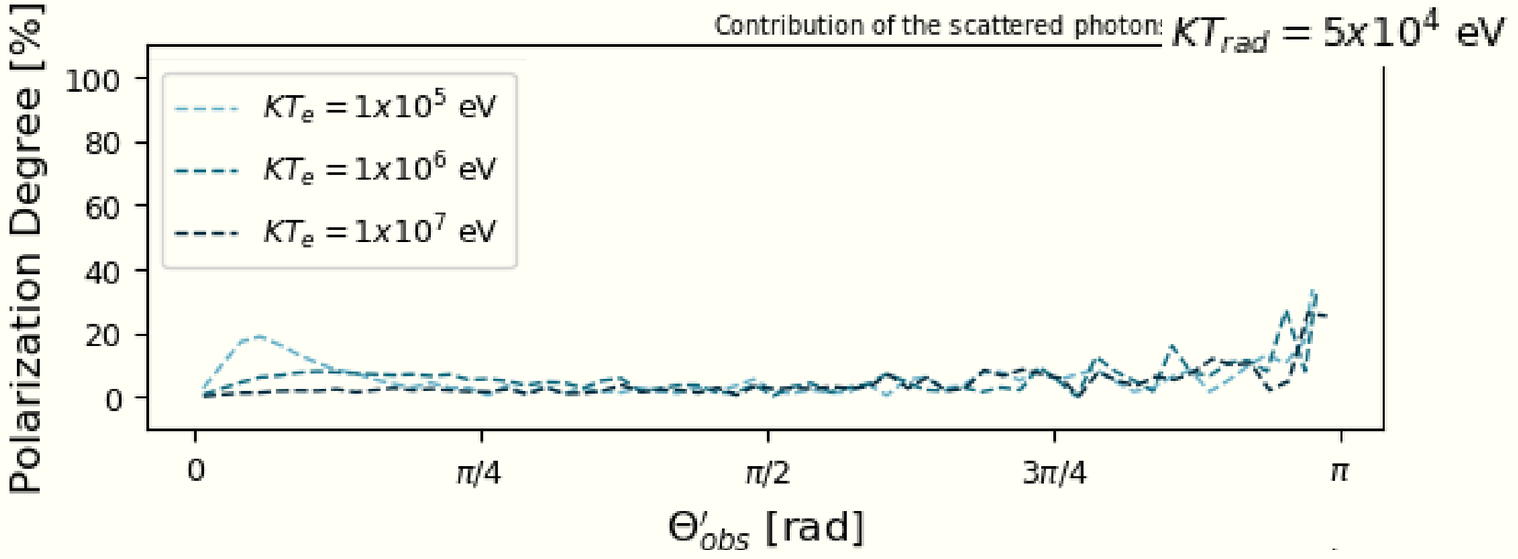
$$\frac{\epsilon_e}{m_e c^2} \ll 1 \rightarrow \text{THOMSON REGIME}$$

$$\epsilon'_e \sim \epsilon_e$$

$$\frac{\epsilon_e}{m_e c^2} \gg 1 \rightarrow \text{KLEIN NISHINA LIMIT}$$

$$\epsilon'_e \sim 1$$





POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

POLARIZATION DEGREES DECREASE WITH THE INCREASE OF PHOTON TEMPERATURES

$$\sigma_{KN} \propto \left(\frac{\epsilon'_e}{\epsilon_e} + \frac{\epsilon_e}{\epsilon'_e}\right) - 2 + 4\left(\vec{P}_e \cdot \vec{P}_e{}'\right)$$

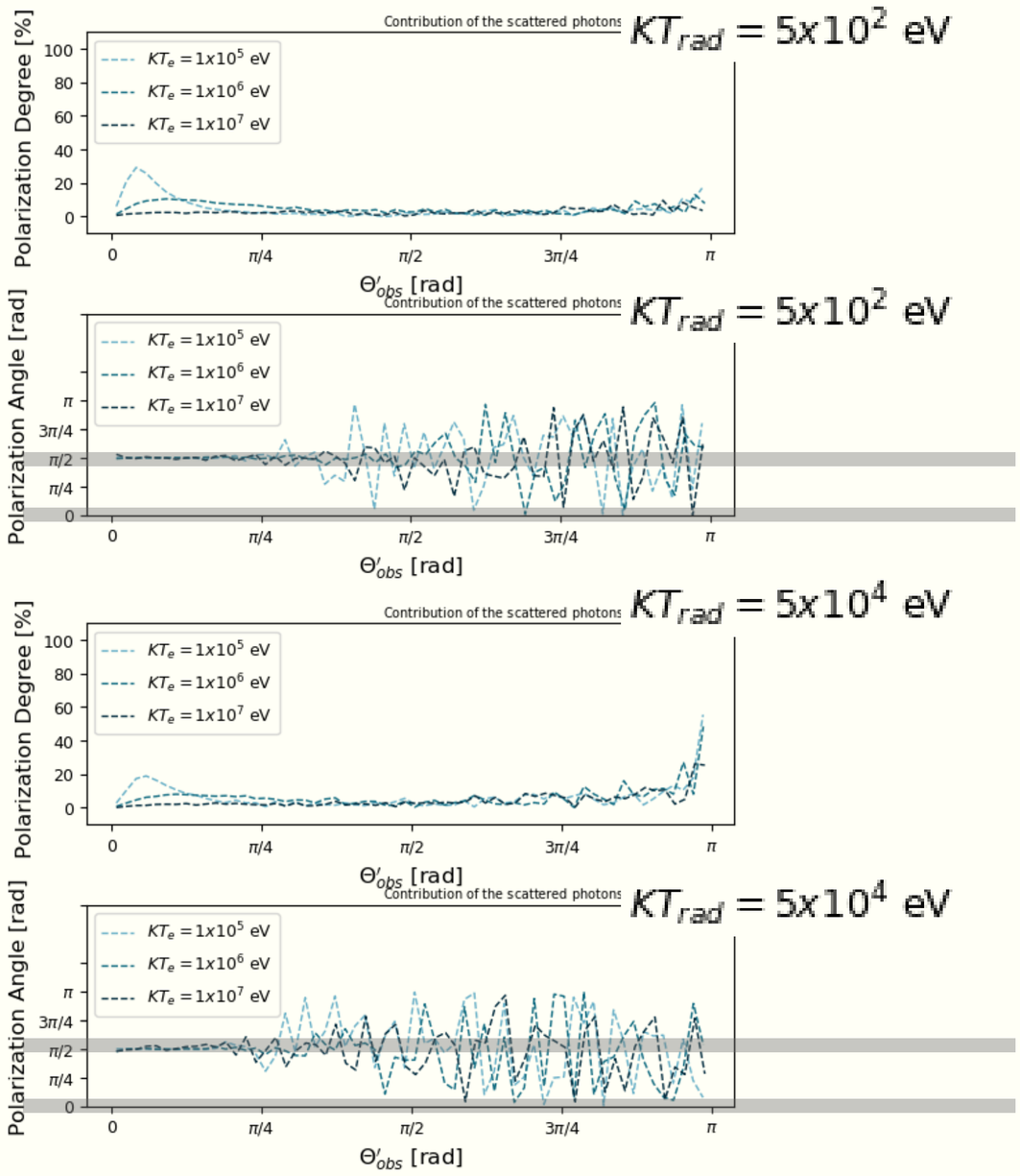
POLARIZATION DEGREES DECREASE WITH THE INCREASE OF THERMAL TEMPERATURES

show polarization angle >

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



VERTICAL POLARIZATION

HORIZONTAL POLARIZATION

shows at which angle is the polarization degree at the maximum and how the polarization angle changes as a function of the viewing angle

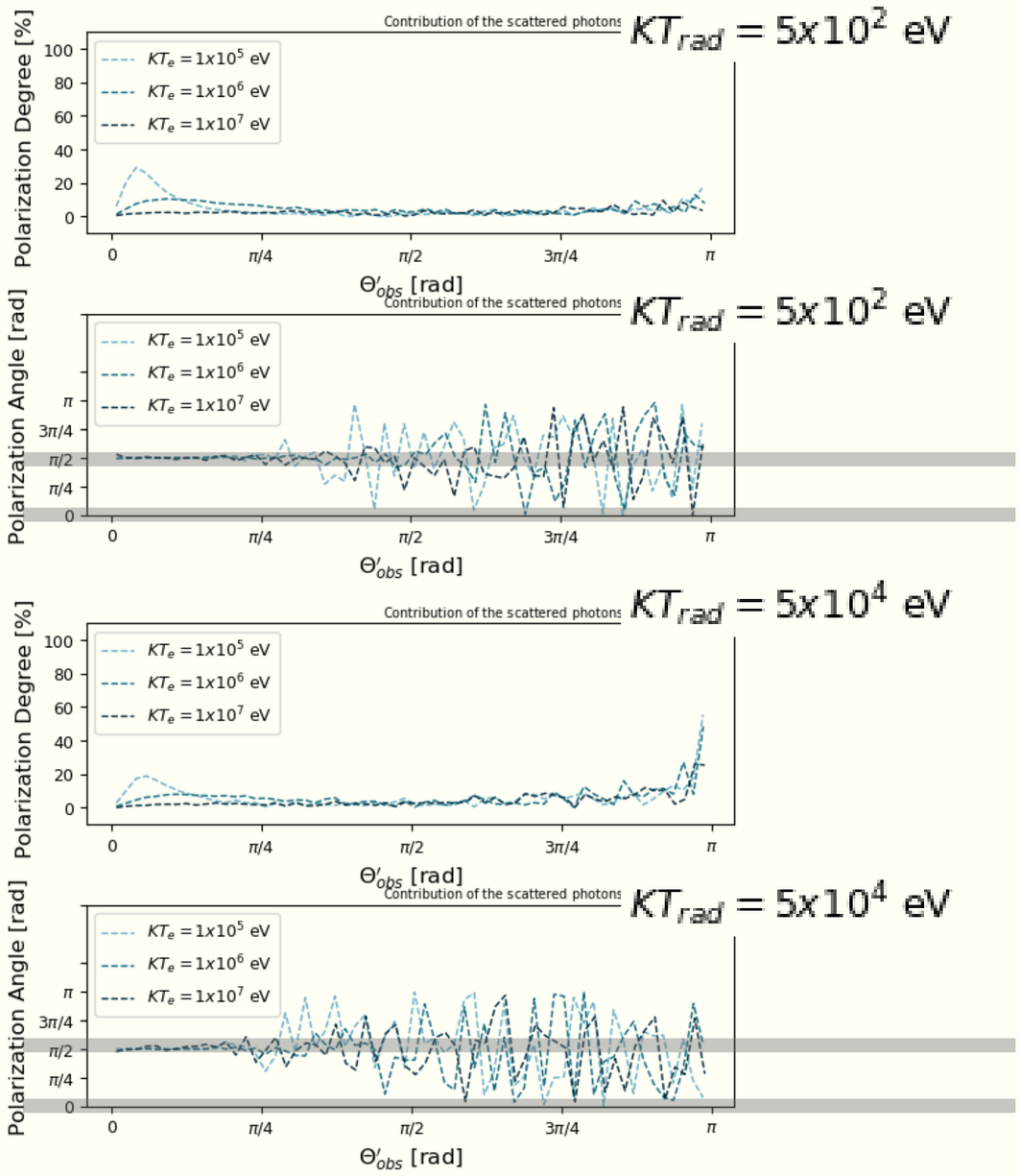
VERTICAL POLARIZATION

HORIZONTAL POLARIZATION

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



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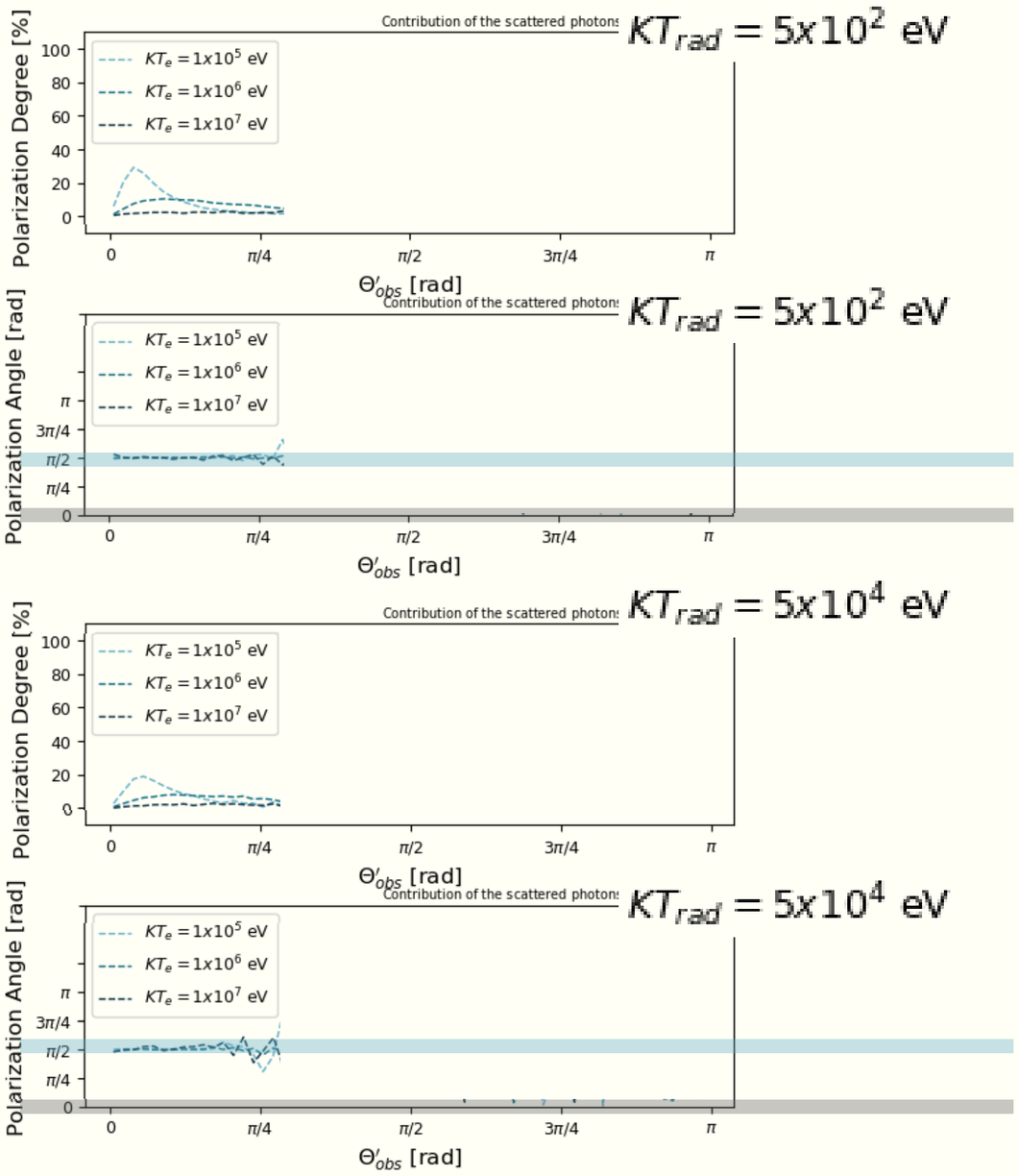
VERTICAL POLARIZATION

HORIZONTAL POLARIZATION

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



VERTICAL POLARIZATION

HORIZONTAL POLARIZATION

POLARIZED PHOTONS SCATTER PREFERENTIALLY PERPENDICULAR TO THEIR ELECTRIC FIELD VECTOR

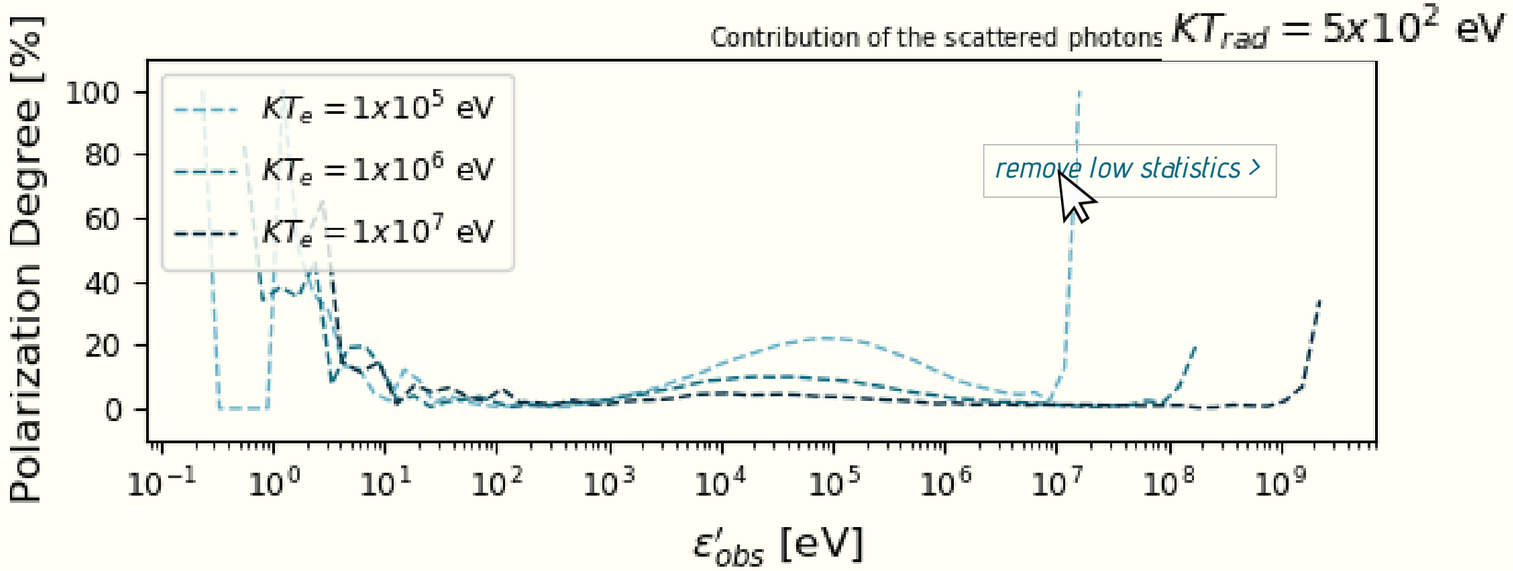
VERTICAL POLARIZATION

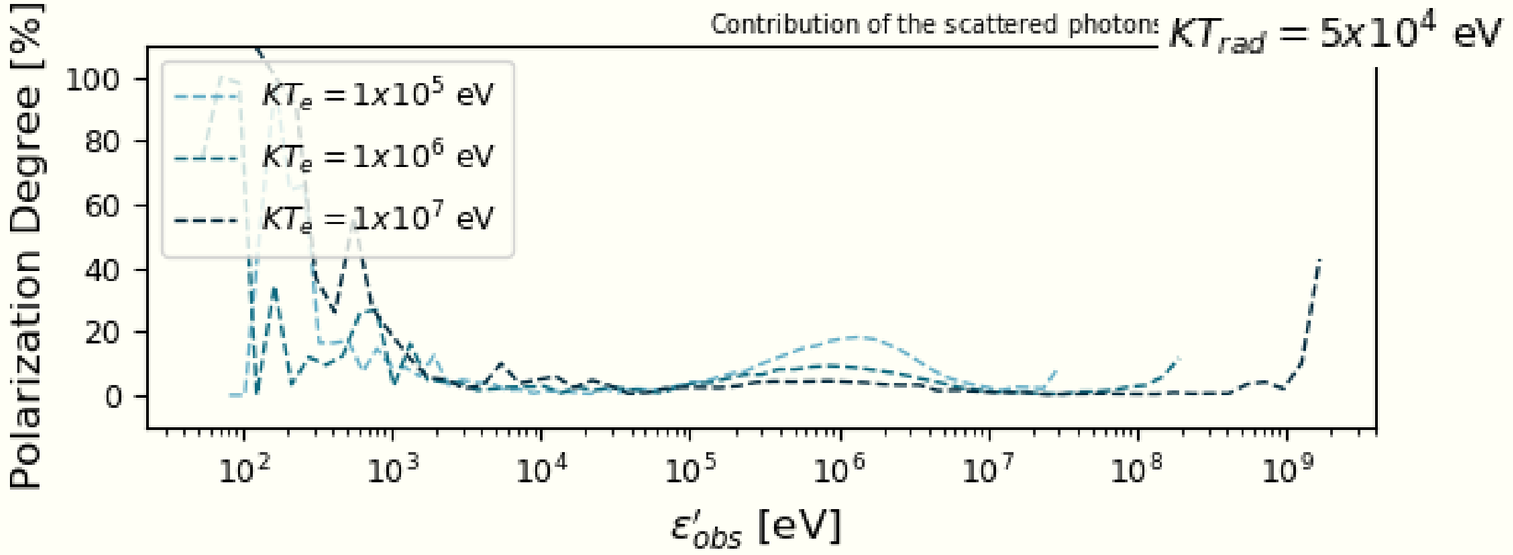
HORIZONTAL POLARIZATION

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

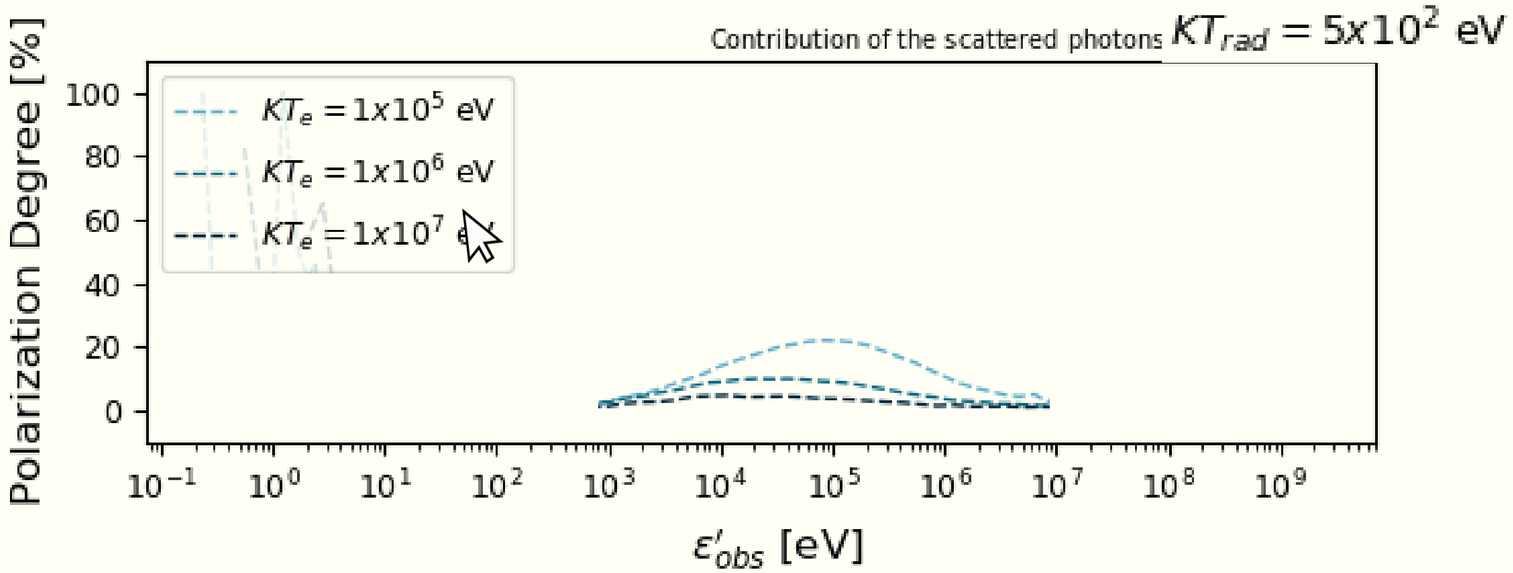


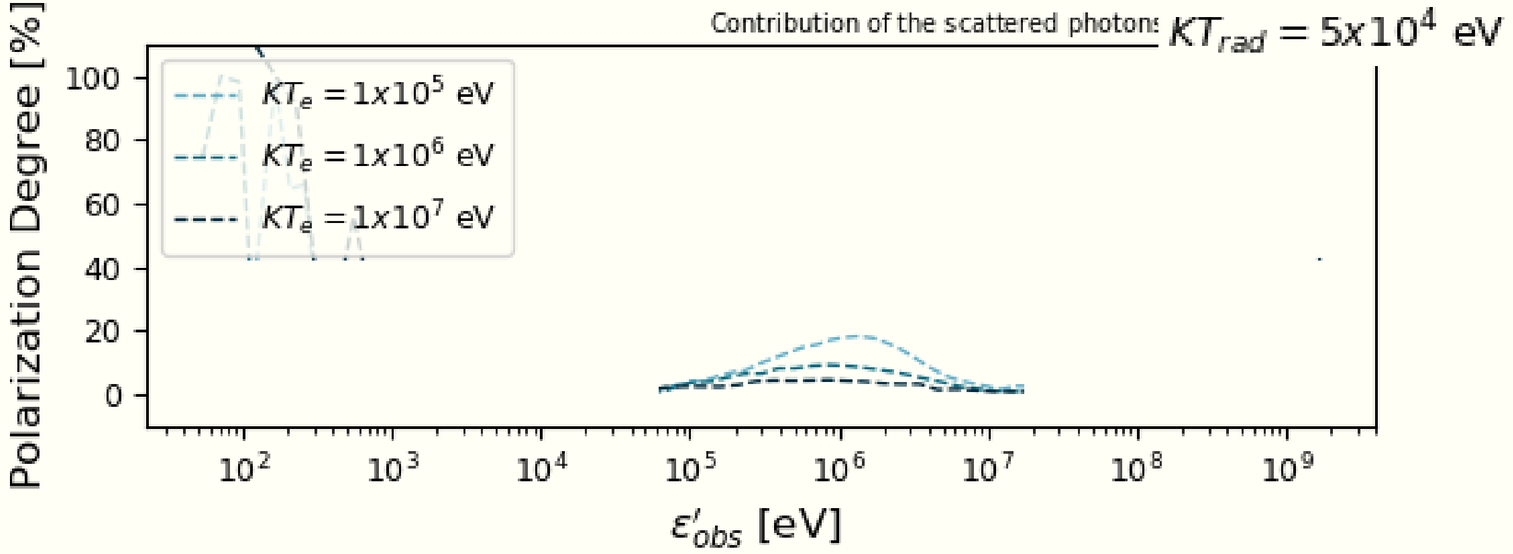


POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY

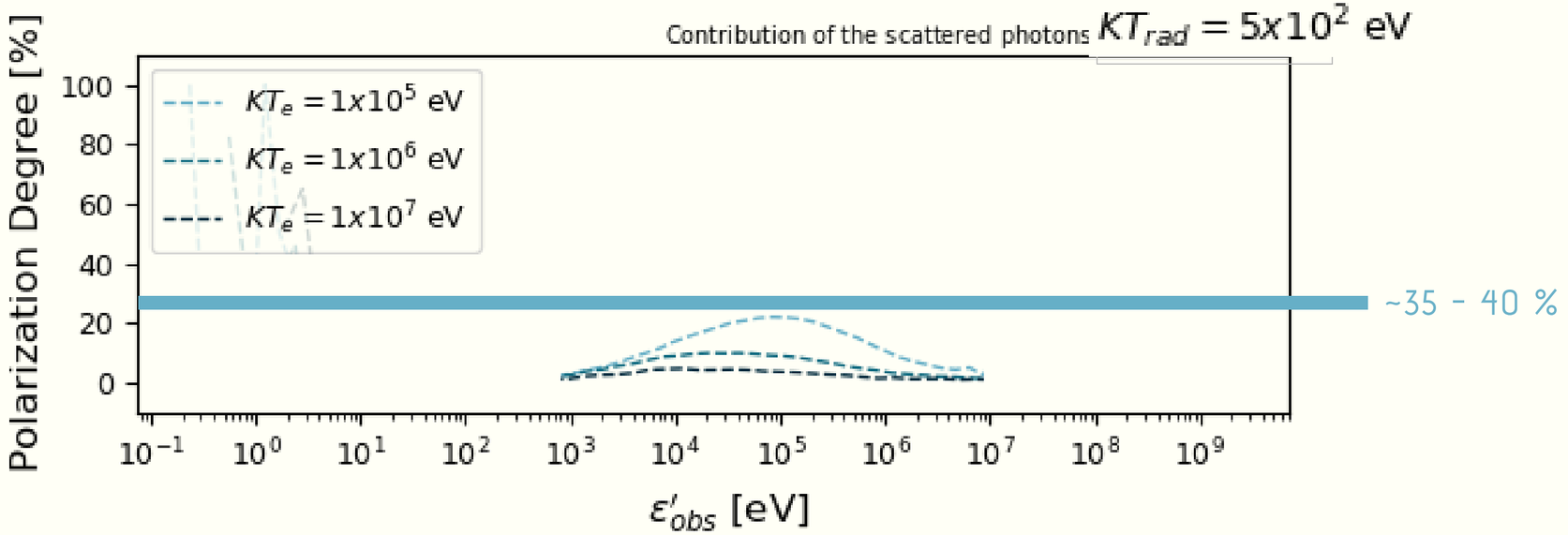




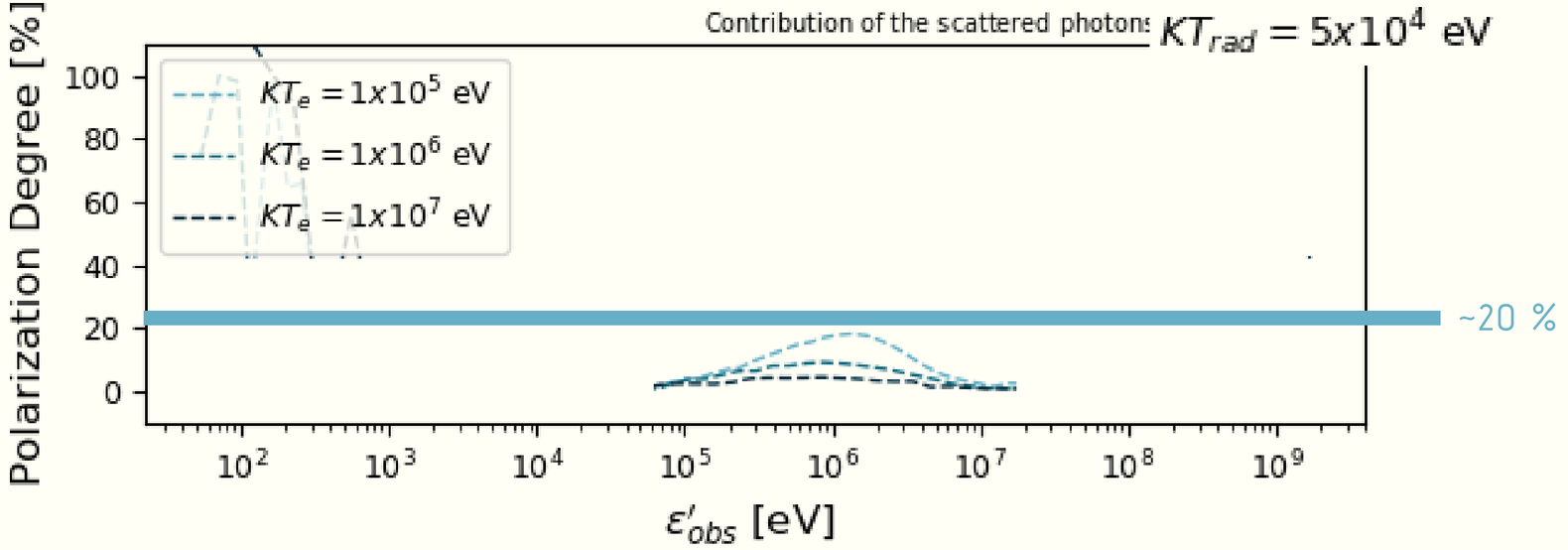
POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



POLARIZATION DEGREES DECREASE WITH THE INCREASE OF PHOTON TEMPERATURES

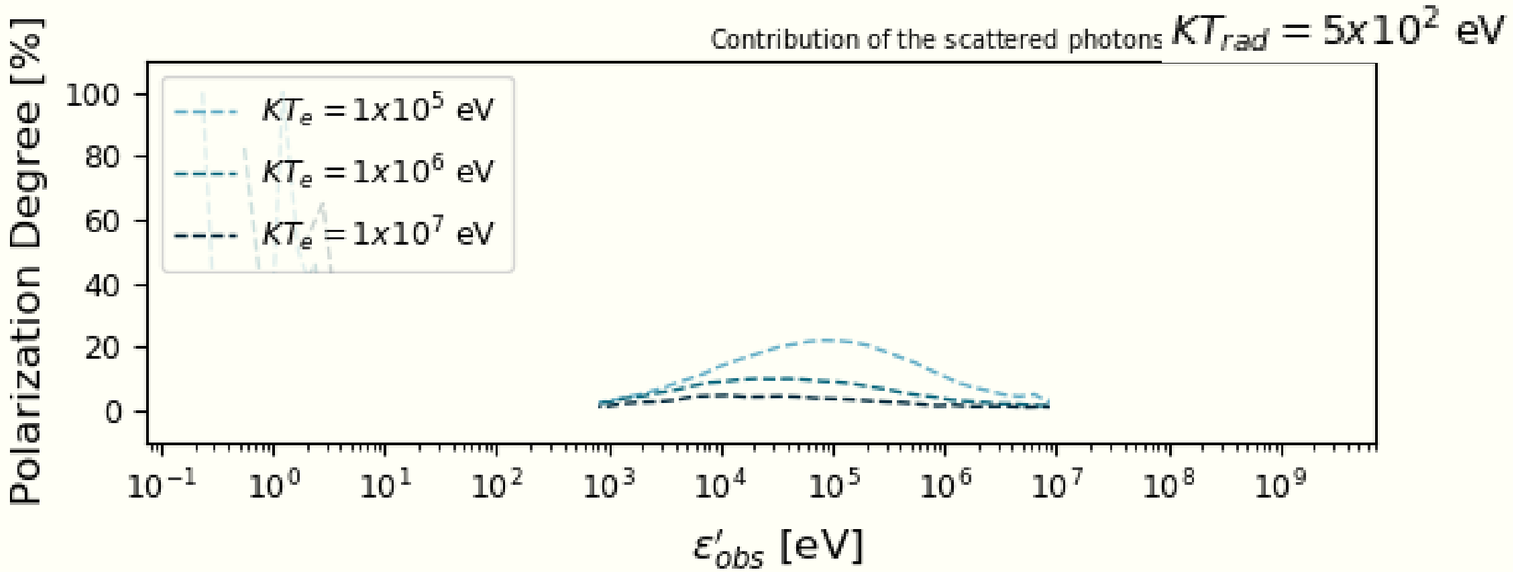


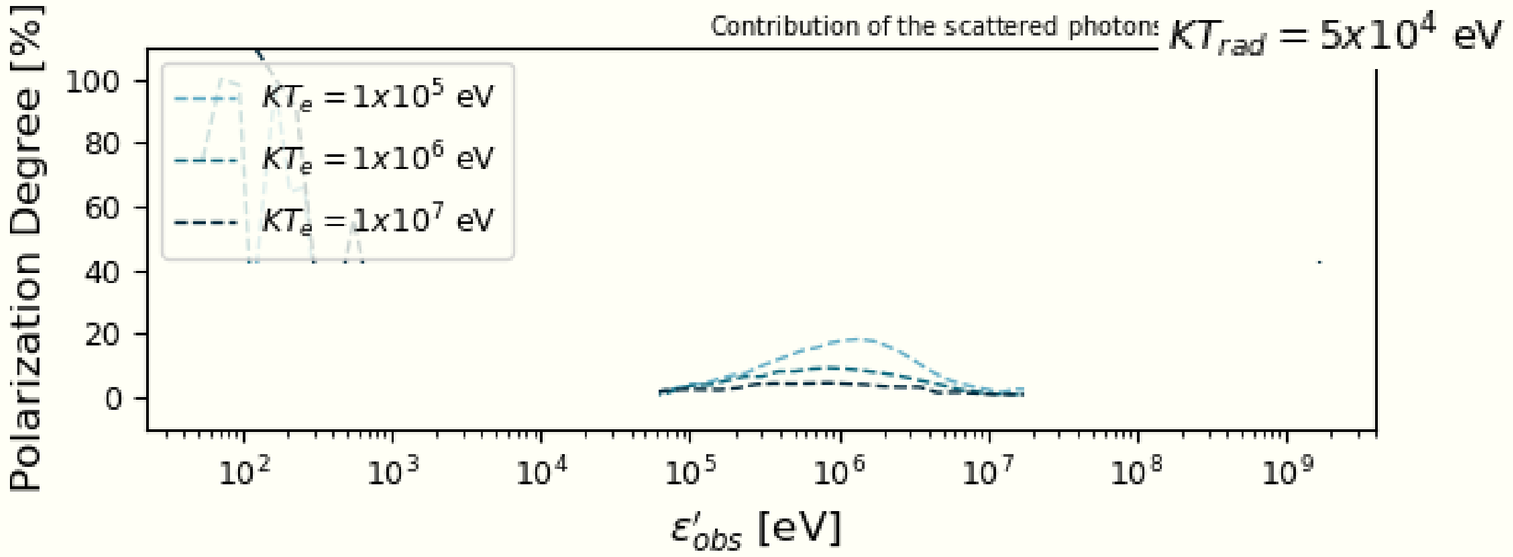
POLARIZATION DEGREES DECREASE WITH THE INCREASE OF THERMAL TEMPERATURES

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



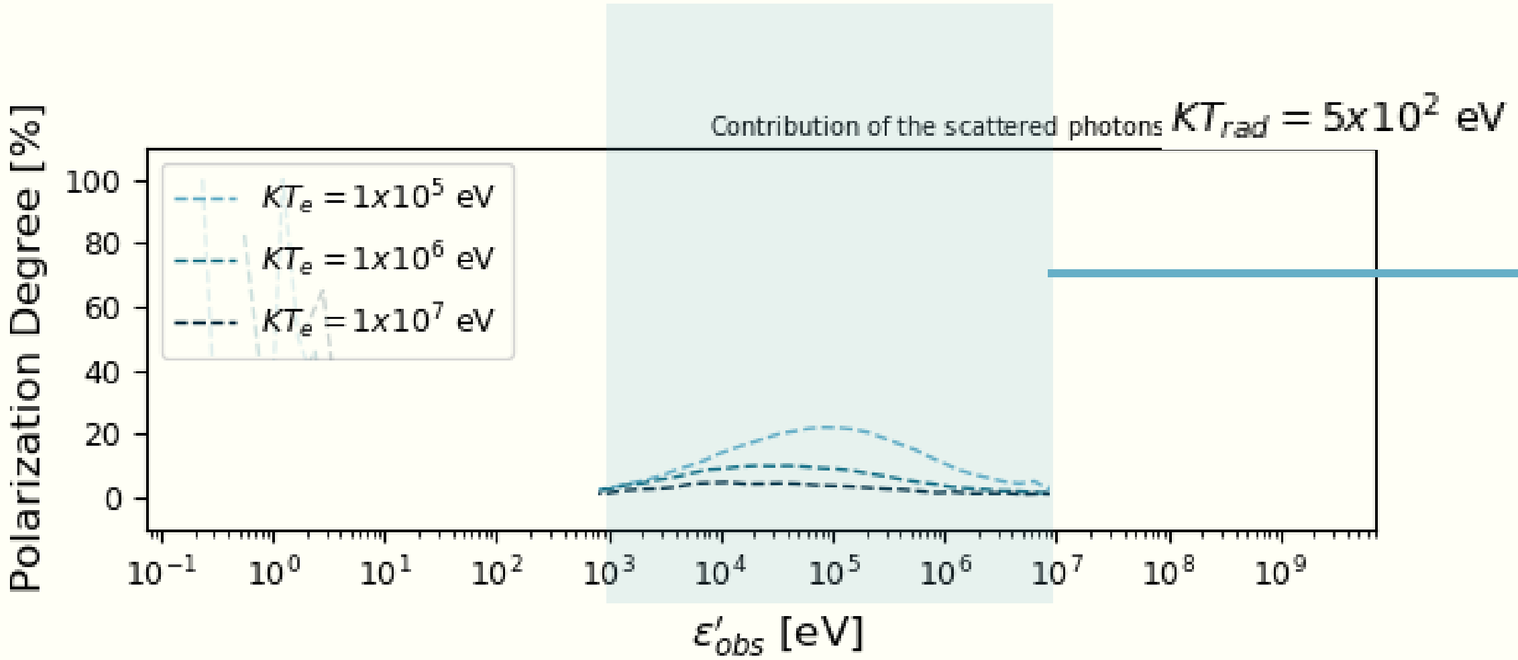


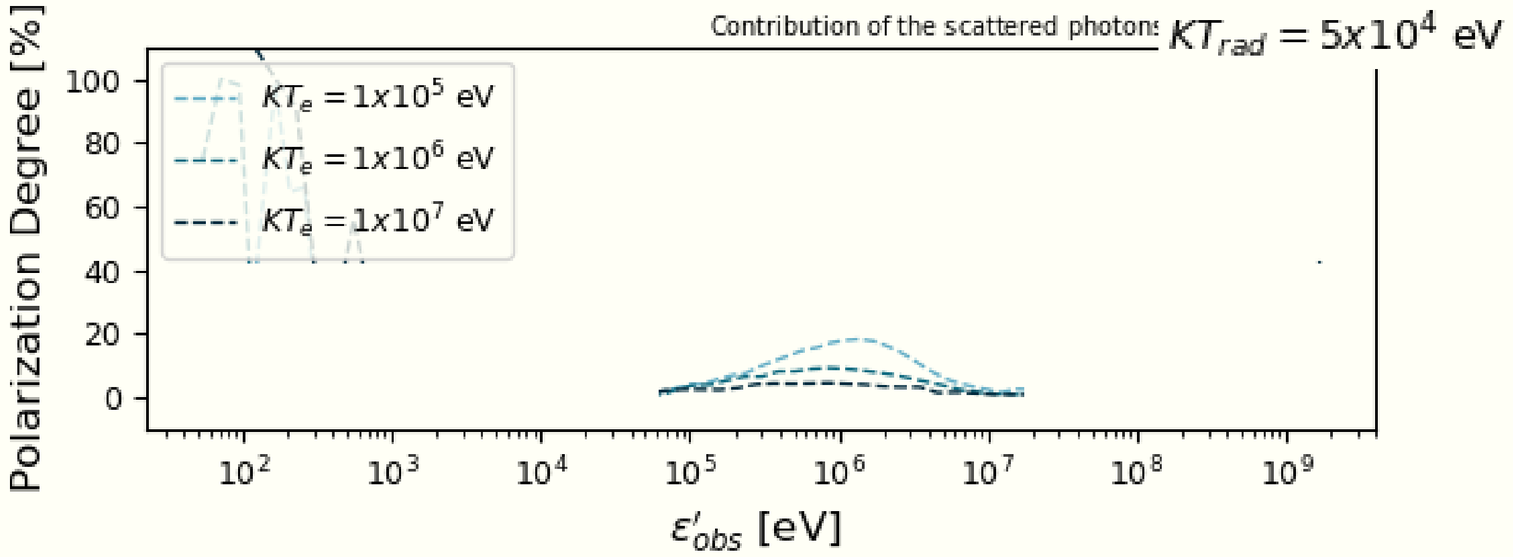
allows the evaluation of which energy band is more convenient in terms of the amplitude of the polarization signal

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY





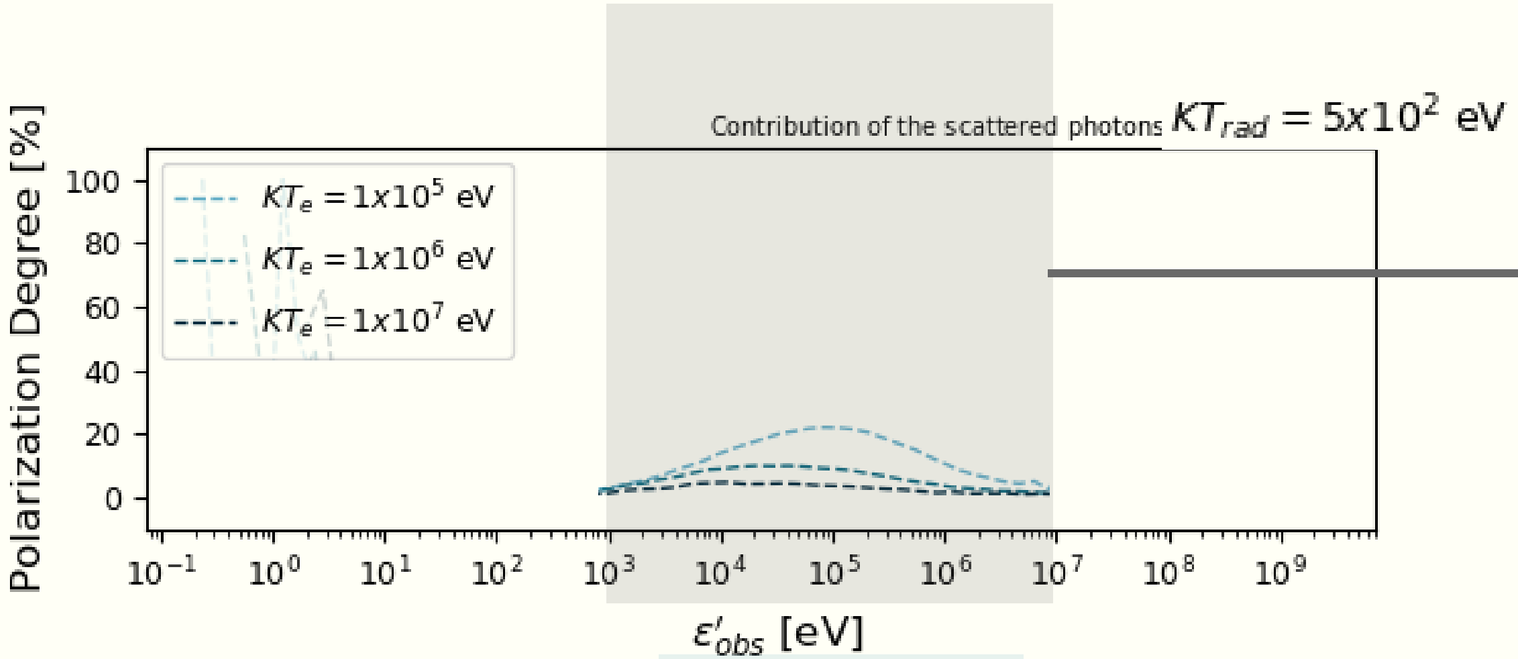
maximum polarization is in the range of 10^3– 10^7 eV

allows the evaluation of which energy band is more convenient in terms of the amplitude of the polarization signal

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

BINNED IN ENERGY



maximum polarization is in the range of 10^3– 10^7 eV

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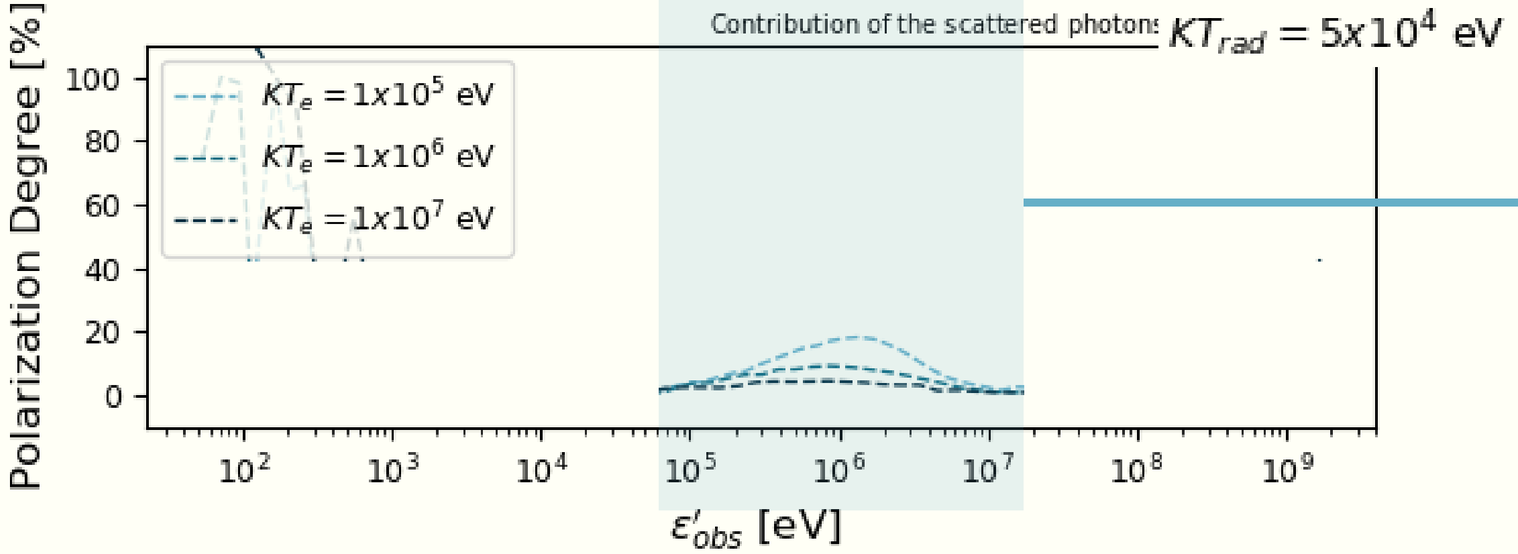
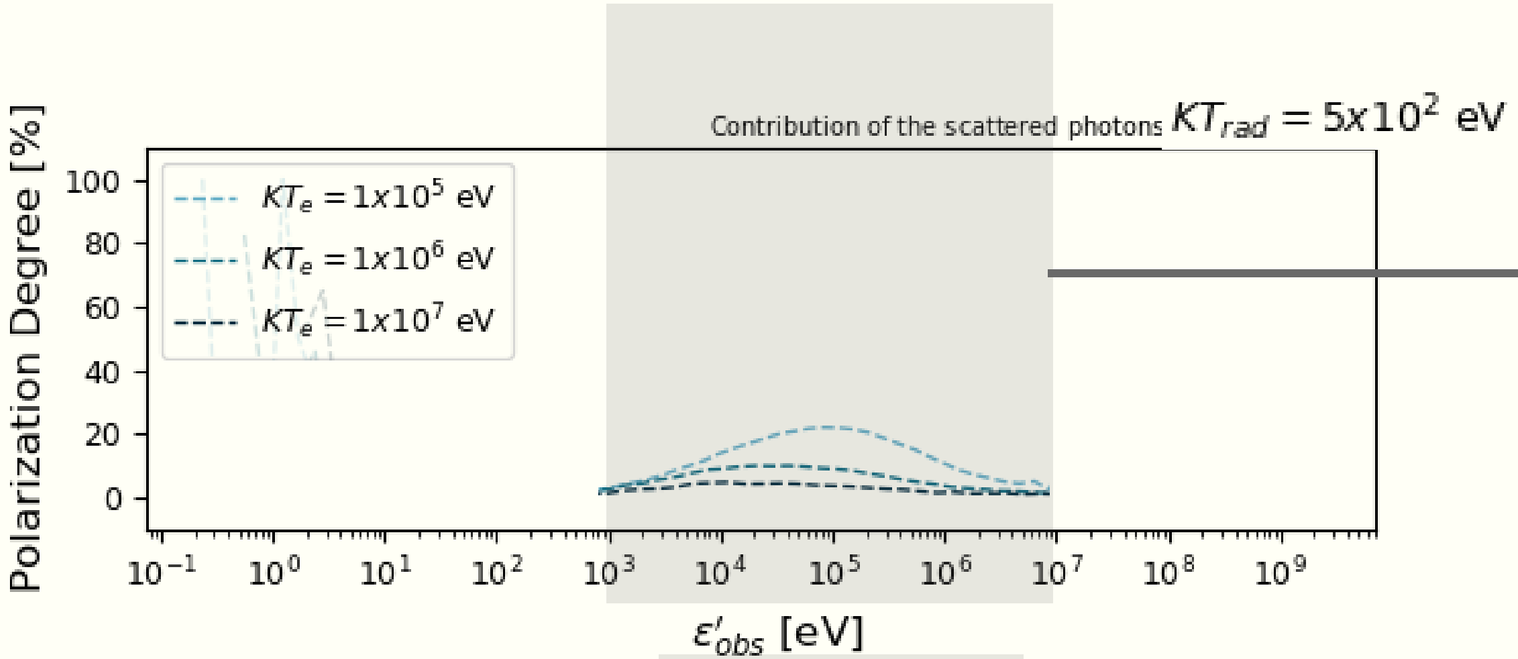


maximum polarization is in the range of 10^5– 10^7 eV

POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

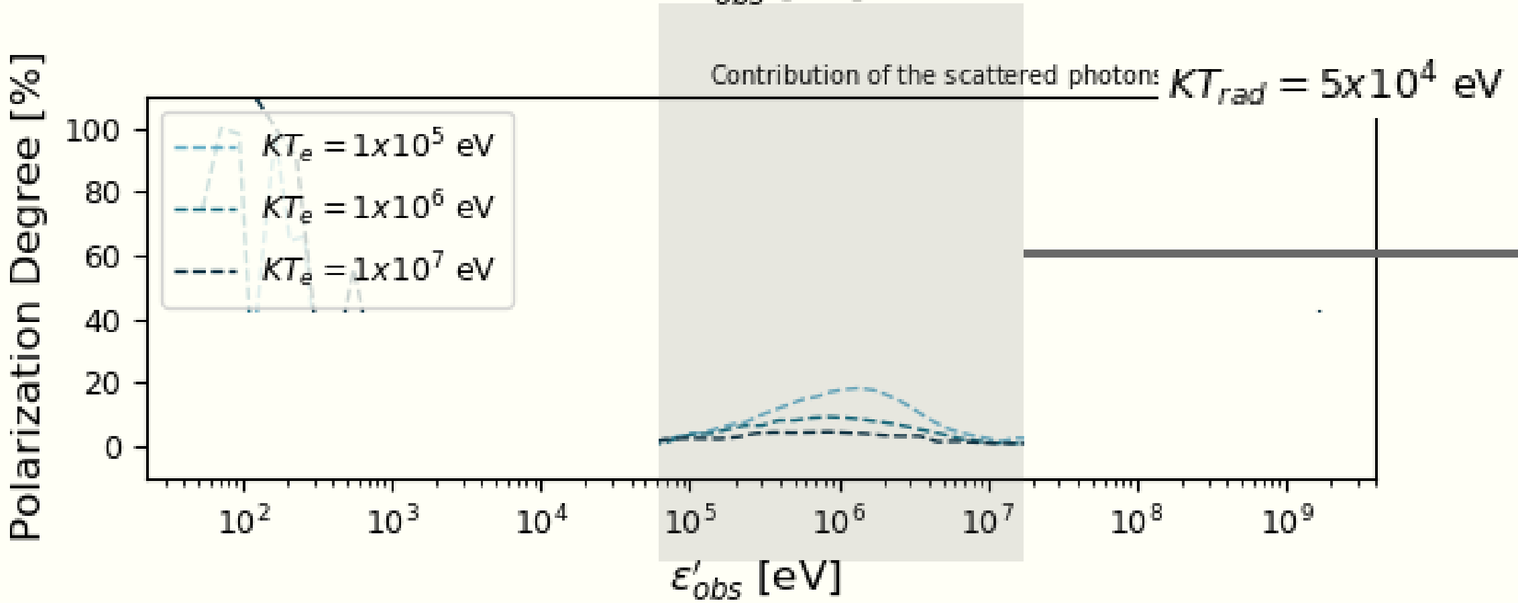
BINNED IN ENERGY



maximum polarization is in the range of 10^3- 10^7 eV

MAXIMUM POLARIZATION SHIFT TO HIGHER ENERGIES FOR HIGHER TARGET PHOTON ENERGIES

THE ENERGY RANGE IS SMALLER FOR HIGHER TARGET PHOTON ENERGIES



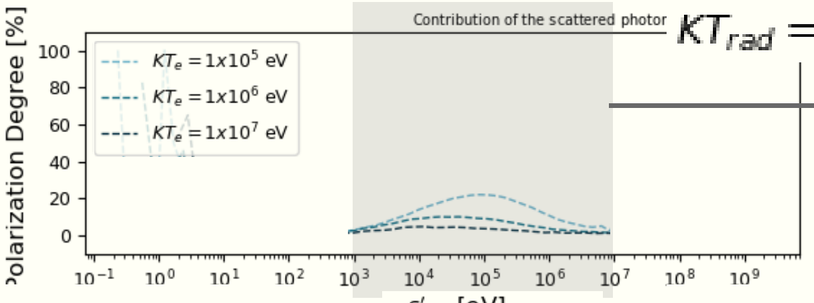
maximum polarization is in the range of 10^5- 10^7 eV

view polarization angles >

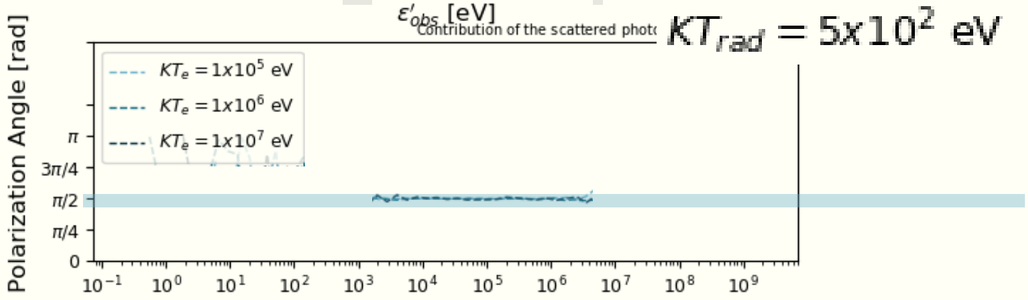
POLARIZATION SIGNAL

BINNED IN VIEWING ANGLE

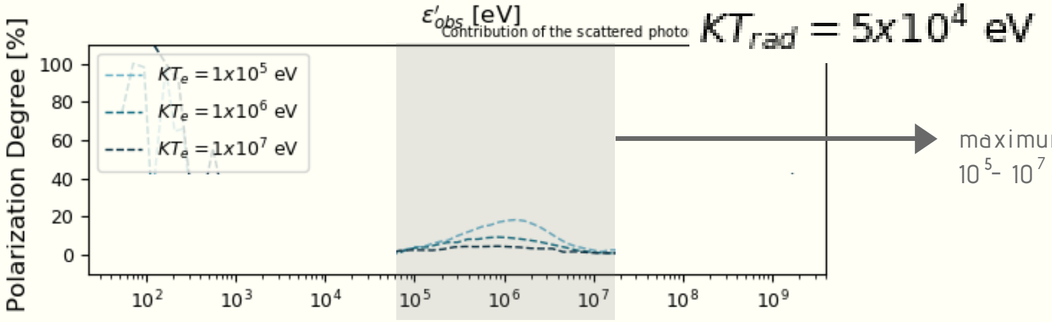
BINNED IN ENERGY



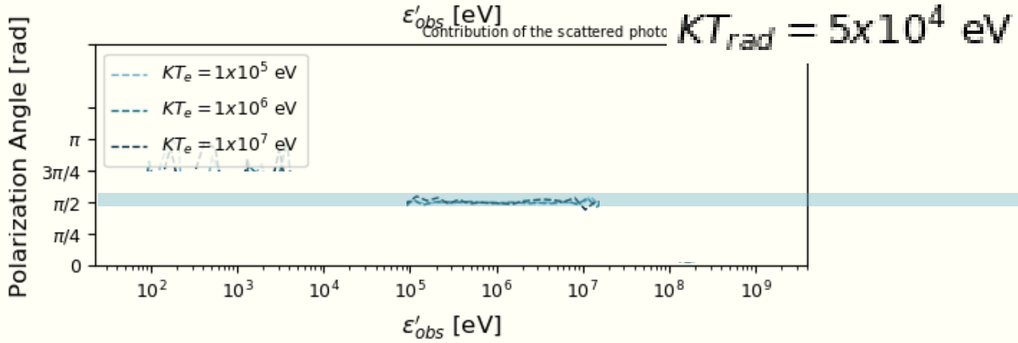
maximum polarization is in the range of 10^3- 10^7 eV



VERTICAL POLARIZATION



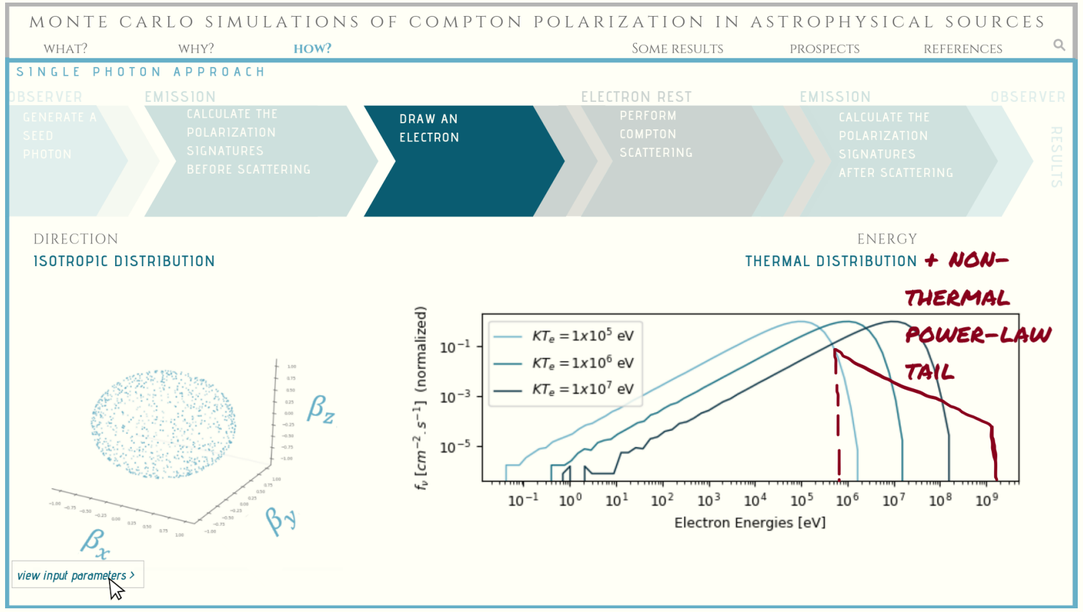
maximum polarization is in the range of 10^5- 10^7 eV



VERTICAL POLARIZATION

NEAR FUTURE

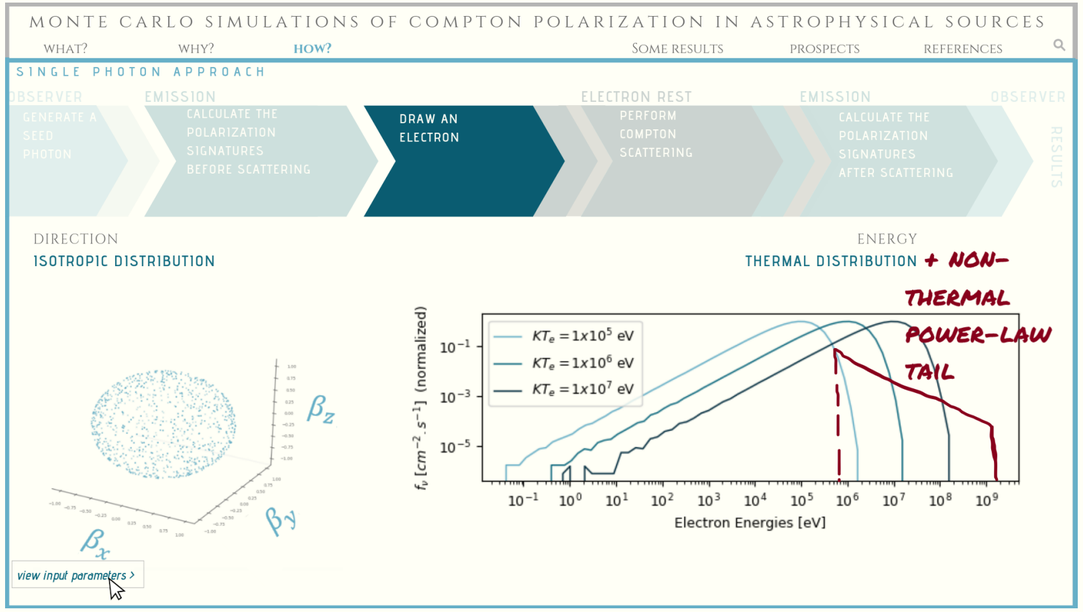
ADD NON-THERMAL POWER-LAW TAIL TO THE THERMAL ELECTRON DISTRIBUTION

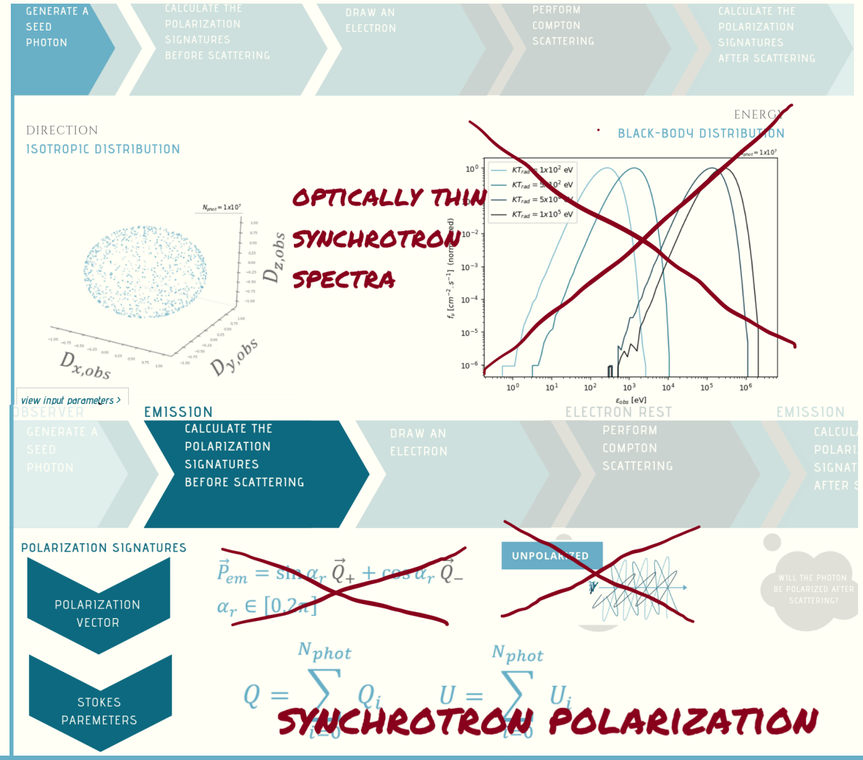


LONG TERM PROSPECTS

NEAR FUTURE

ADD NON-THERMAL POWER-LAW TAIL TO THE THERMAL ELECTRON DISTRIBUTION





LONG TERM PROSPECTS

ADD SYNCHROTRON POLARIZATION TO SIMULATE THE TRANSITION FROM LOW-ENERGY TO HIGH- ENERGY POLARIZATION

Böttcher, M., 2019. Progress in Multi-wavelength and Multi-Messenger Observations of Blazars and Theoretical Challenges. *Galaxies*, 7(1), p.20.

Holder. J., 2019. *Gamma-Ray Binaries*, lecture notes, Fermi Summer School 2019, University of Delaware, delivered 30 May 2019.

Matt, G., Feroci, M., Rapisarda, M. and Costa, E., 1996. Treatment of Compton scattering of linearly polarized photons in Monte Carlo codes. *Radiation Physics and Chemistry*, 48(4), pp.403-411.

Tamborra, F., Matt, G. and Bianchi, S., 2013. MoCA: a Monte Carlo code for accretion in Astrophysics. Ph.D. Thesis. Roma Tre University,

INPUT PARAMETERS

BULK LORENTZ FACTOR

$\Gamma = 10$

TARGET PHOTON ENERGIES

$KT_{rad} = 5x10^{2}$ eV

$KT_{rad} = 5x10^{4}$ eV

THERMAL ELECTRON ENERGIES

$KT_{e} = 1x10^{5}$ eV

$KT_{e} = 1x10^{6}$ eV

$KT_{e} = 1x10^{7}$ eV

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

BOOST >

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

TRANSFORM >

ELECTRON REST

PERFORM COMPTON SCATTERING

TRANSFORM >

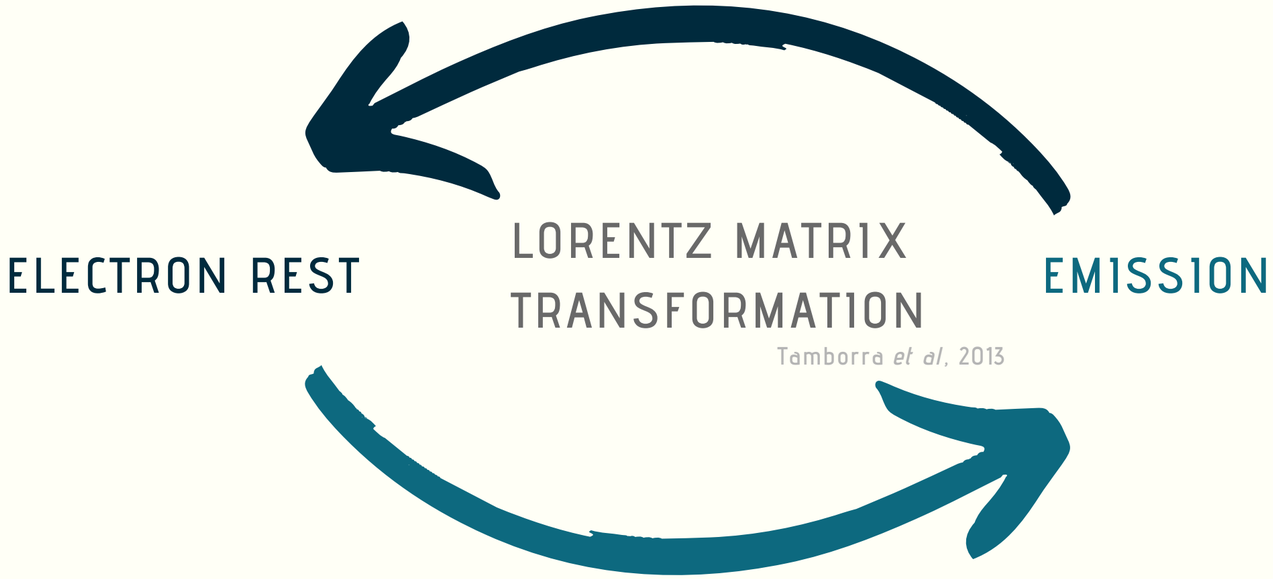
EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

BOOST >

OBSERVER

RESULTS



Tamborra *et al*, 2013

SINGLE PHOTON APPROACH

OBSERVER

GENERATE A SEED PHOTON

EMISSION

CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING

DRAW AN ELECTRON

ELECTRON REST

PERFORM COMPTON SCATTERING

EMISSION

CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING

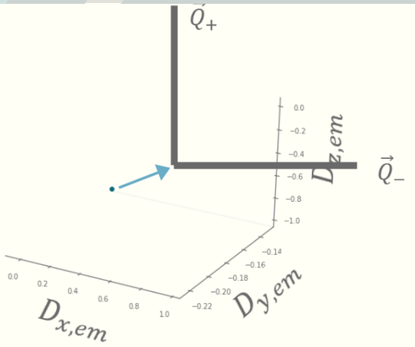
OBSERVER

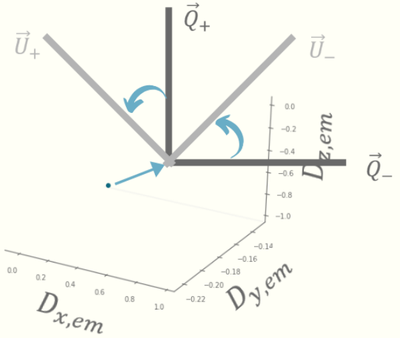
RESULTS

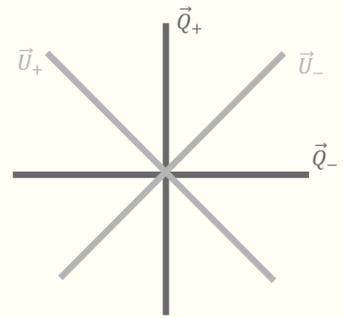
CALCULATE THE POLARIZATION VECTOR

$$\vec{P}_{em} = \sin\alpha_r \, \vec{Q}_+ + \cos\alpha_r \, \vec{Q}_-$$

$$\alpha_r \in [0,2\pi]$$







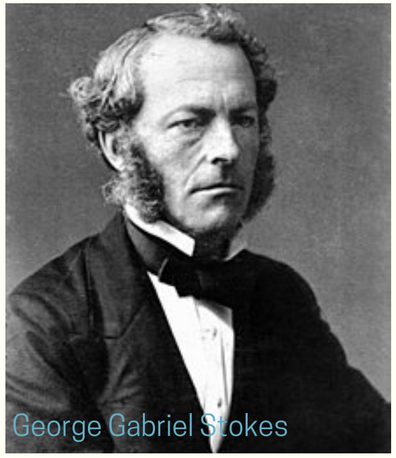
CALCULATE THE CONTRIBUTIONS OF THE PHOTON TO THE STOKES PARAMETERS

$$Q_i = \left(\vec{P}_{em} \cdot \vec{Q}_+\right)^2 - \left(\vec{P}_{em} \cdot \vec{Q}_-\right)^2$$

$$U_i = \left(\vec{P}_{em} \cdot \vec{U}_+\right)^2 - \left(\vec{P}_{em} \cdot \vec{U}_-\right)^2$$

view for all photons >

POLARIZATION SIGNATUTES


George Gabriel Stokes

SINGLE PHOTON APPROACH

OBSERVER → EMISSION → GENERATE A SEED PHOTON → CALCULATE THE POLARIZATION SIGNATURES BEFORE SCATTERING → DRAW AN ELECTRON → ELECTRON REST → PERFORM COMPTON SCATTERING → EMISSION → CALCULATE THE POLARIZATION SIGNATURES AFTER SCATTERING → OBSERVER → RESULTS

STOKES PARAMETERS ARE ADDITIVE

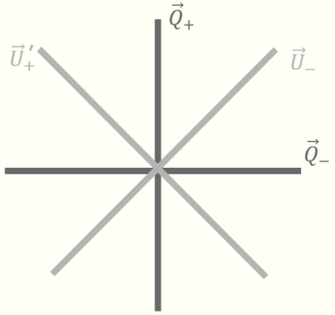
$$Q' = \sum_{i=0}^{N_{scatt}} Q'_i$$

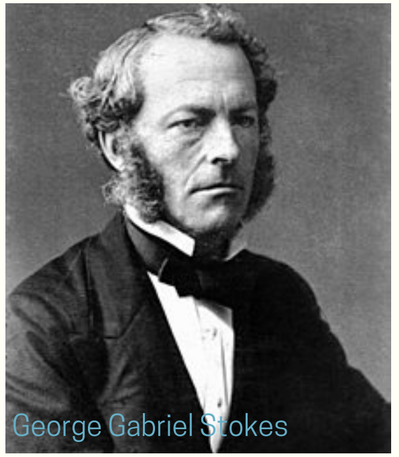
$$U' = \sum_{i=0}^{N_{scatt}} U'_i$$

POLARIZATION SIGNATUTES

$$\Pi' = \frac{\sqrt{Q'^2 + U'^2}}{N_{scatt}}$$

$$\chi' = \frac{1}{2}\tan^{-1}\frac{U'}{Q'}$$

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